BBC

FOCUS MAGAZINE Collection

VOL.07

THE SCIENTIFIC GUIDE TO YOUR FUTURE LIFE

Elon Musk's mind-controlled tech

Are driverless cars really safe?

How science will help you stay healthy past 100

The next-generation drones taking to the skies and space

Goodbye Alzheimer's

Robot butlers for your smart home

The future of food: lab-grown burgers

The big breakthrough that will beat cancer

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Your smart life

Anyone remember Zip drives? If you're old enough to recall the floppy disk (yes, youngsters, the 'save' icon was once a physical object), you may also remember wishing that they held more than 1.4MB of data. Then in the mid-1990s, the Zip drive came along, with its whopping 100MB per disk. It was soon superseded by the more flexible flash drive that pops in and out of a USB port.

How about pagers? Back in the 20th Century, the seemingly impossible dream of being able to contact somebody at any time, no matter where they were, became a reality. Gone are the days of us all using those basic beeping/vibrating devices (now reserved for doctors only). Smartphones rule – at least for the time being. One day, there may be no need for smartphones as separate devices, instead we'll have gadgets integrated into our heads and hands. That's how it works with technology – our world just keeps getting smarter and more streamlined.

In this special issue, we take a look at the big tech trends and innovations that will change the way you live tomorrow and in years to come. The first section reveals the tech that will infilitrate your home – whether that's on Earth or another planet like Mars. The second section investigates the big breakthroughs that could one day eradicate diseases such as cancer and Alzheimer's. And the final section takes you on the ultimate journey – unlike the humble pager, jetpacks and flying cars are the future.

Daniel Bennett, Editor

COVER ILLUSTRATION: ANDY POTTS THIS PAGE: GETTY

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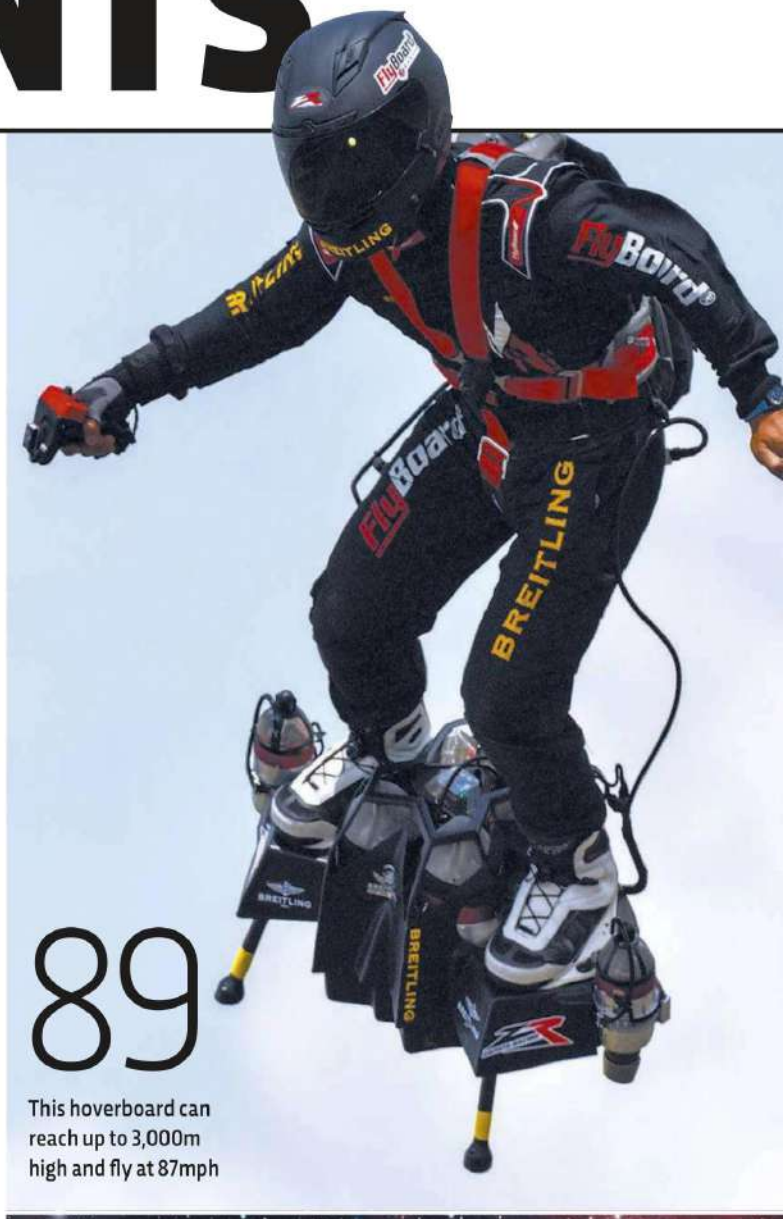

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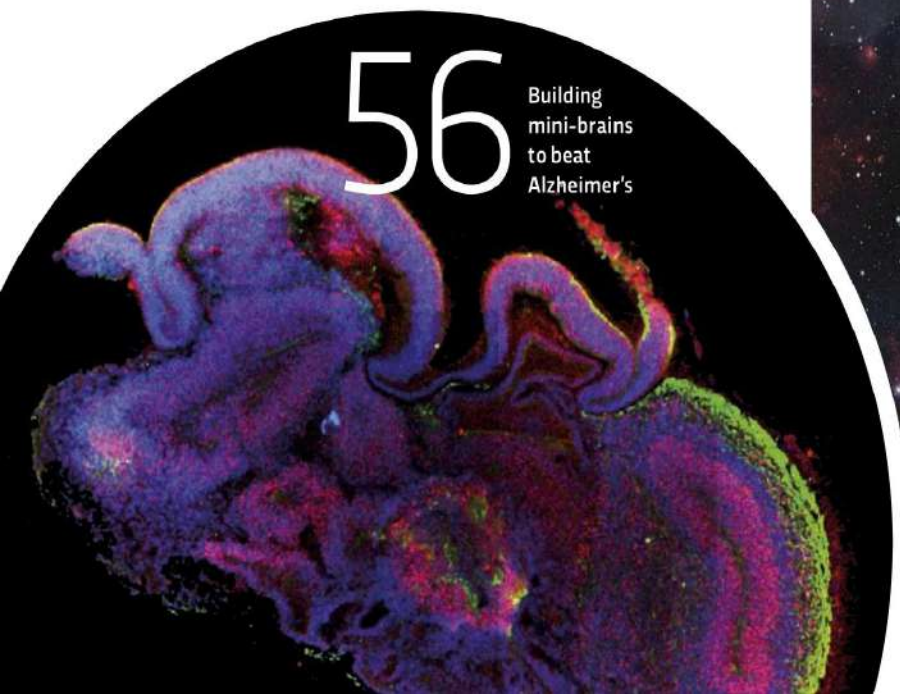
This hoverboard can reach up to 3,000m high and fly at 87mph



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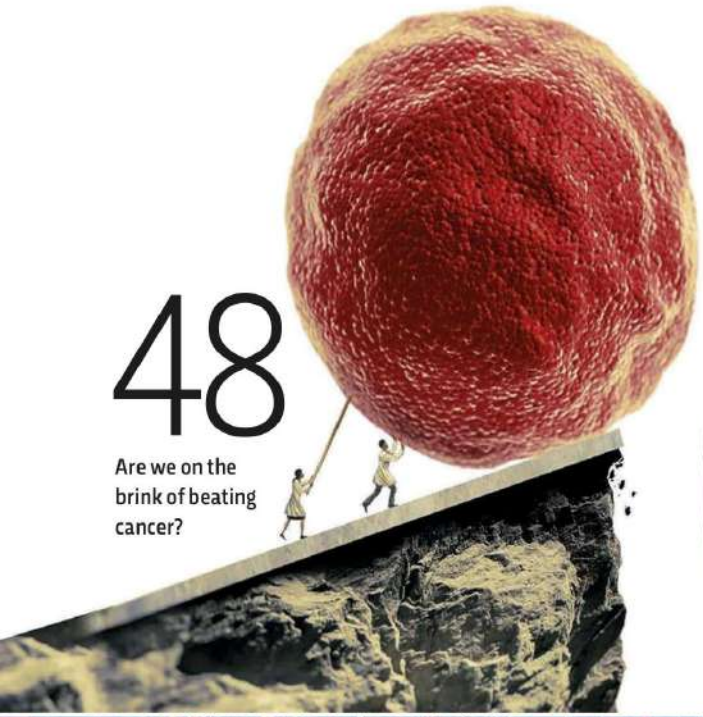

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GETTY

The world is getting ever smarter. In this section, we take a look at how smart technology is revolutionising our home lives.

HOME

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YOUR FUTURE SMART HOME

Bricks that heal, paint that never stains and air conditioned beds, let us show you around the home of tomorrow that you could build today...

WORDS: **LUKE EDWARDS** ILLUSTRATIONS: **DANIEL BRIGHT**

OUTSIDE

WALLS

Self-healing is no longer reserved for video game characters: buildings can do it too. Scientists have created a coating that contains microcapsules. When a coated concrete surface becomes damaged, the capsules break open and release a solution, which fills the crack and turns into a water-resistant solid when exposed to sunlight.

PAINT

Self-cleaning paint is one development aimed at keeping houses looking new. One company, StoLotusan, has developed a paint that won't let water adhere to it. Slap it on your property, then when it rains, any dirt will be lifted from the surfaces of the walls and washed away. The fact it's available in 500 colours is just a bonus.

WINDOWS

Windows that change their tint automatically aren't new, but a team at the University of Texas has developed glass that's able to block the heat-producing part of light. Thanks to a framework of electrically conductive nanocrystals embedded in a glassy material, near-infrared light can be blocked by adding an electronic charge. Up to 90 per cent of near-infrared light and 80 per cent of visible light can be blocked. This could mean huge energy savings in buildings in the near future.

ENERGY

Renewable energy sources are what the future is all about. They help homes become self-reliant and go off-grid. Some energy suppliers pay you to pump juice back into the grid. The Smartflower POP is one of the most attractive and efficient examples of solar panels yet. Smartflower POP will 'bloom' open in the morning and close up at night. So it's space-efficient, too. Best of all, you can take it with you when you move!

Toshiba's Symbio is both a security camera and Alexa speaker

Smartflower POP solar panels open in the day and close at night

The robot lawnmower Husqvarna Automower 305

SECURITY

The old-fashioned trick of leaving lights and radios on to fool burglers into thinking there's someone home has already been given a 21st-Century upgrade. Devices such as Alexa can be used to switch on lamps and stereos while you're out, but Mitipi's Kevin, available to pre-order, is the next step. Kevin, named after Macaulay Culkin's character from the film *Home Alone*, will use geo-fencing to determine when you and your phone leave the house before switching itself on.

If any visitors – wanted or unwanted – decide to venture up your garden path, it's already possible to keep an eye on them remotely by installing cameras that link to your smartphone and display real-time footage from your front door. The EZVIZ Lockout Smart Door Viewer due on sale this year sees facial-recognition software integrated into the system.

LAWNMOWER

Robot lawnmowers are the way forward. Thanks to laser markers, the Husqvarna Automower 305 can sense garden boundaries, recharge and will never bring muddy boots into the house. Better yet, the EcoMow turns the grass it cuts into biofuel pellets to use as fuel.

THE MOWER

1986
Remember mixing together diesel and oil for two-stroke? Or pushing a heavy, noisy and smelly mower about?

2016
Autonomous mowers can charge themselves and stay within boundaries to keep the plants safe.

2036
Genetically modified grass that grows to a uniform length could eliminate the need for mowing.

GETTY, ALAMY

LIVING ROOM

TELEVISION

At the CES tech show earlier this year, big screens were big news. King of them all was Samsung's aptly-named The Wall: a 146-inch 4K TV. Samsung was also showing off smaller 8K televisions (16 times the pixel count of a full HD TV), which should be available before the end of the year. Meanwhile, LG was showcasing OLED screens that can be rolled up like a newspaper. Panasonic, on the other hand, has released a prototype of a television screen that's transparent when not in use. Soon our TV screens will double up as windows or walls.

LIGHTING

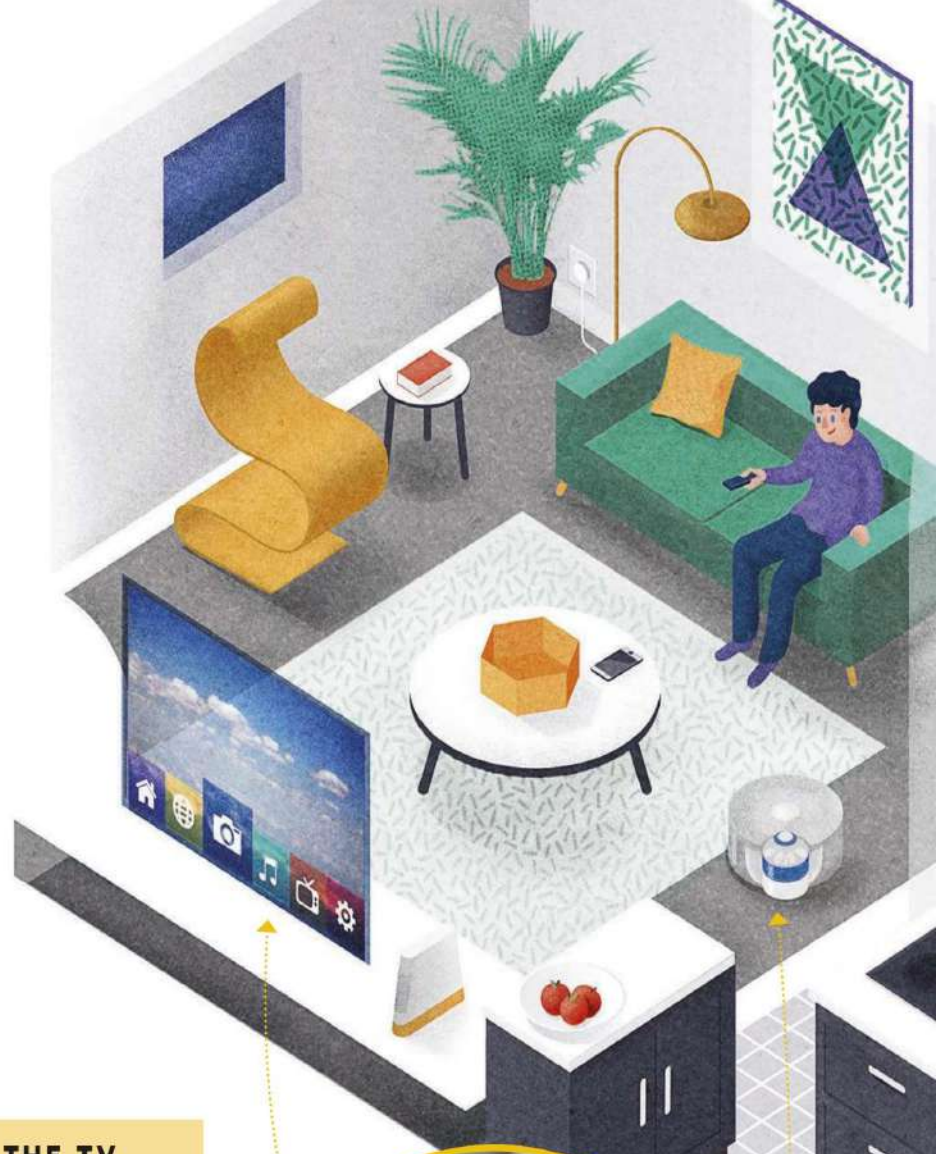
Philips Hue is a wireless lighting system that lets you control light colour and intensity from a smartphone app. Now the new Hue Sync app lets you coordinate your lights with whatever you're doing on your computer, so lights can 'dance' to the beat of your music or mimic the colours you see onscreen. Mipow's Playbulb goes one better. As well as being a pretty nifty light bulb, it's also a wireless speaker. So you can use it as a nightlight and play a favourite lullaby when you put the kids to bed. More of a party animal? Set it to pulse in technicolour.

CLEANING

Forget cordless vacuum cleaners, hands-free, self-charging, self-docking robot vacuum cleaners, which navigate around a room using complex software, leave you to put your feet up. The next step? Ones that will empty themselves so human hands never need touch the smart robo-servants ever again.

ROBOT BUTLER

Robot butlers were also on display at CES this year. While the CLOi stopped working during LG's presentation, humanoid robot Aeolus offered the most promise for a chore-free future – vacuuming and fetching things from other rooms. Meanwhile, Facebook superboss Mark Zuckerberg is currently working on improving his virtual butler, modelled on Jarvis from *Iron Man*.



THE TV

1986

Cathode ray tube TVs dominated living rooms in the 1980s and often had a video recorder nestled underneath. Satellite services arrived on the scene a few years later.

2016

Large flatscreen LCD TVs are the norm today, often equipped with 'smart TV' features and linked up to a recording device, streaming box, or games console.

2036

Expect high-definition televisions of the future to be pretty much invisible until you turn them on, masquerading the rest of the time as a wall or window.

LG's flexible screen can be rolled up and popped in a cupboard until needed

Dyson's 360 Eye uses complex calculations to clean your house

The Bixby-enabled Samsung Family Hub

Even novices can cook to perfection with a smart sous-vide

KITCHEN

HEAD CHEF

One of the most useful gadgets on display at CES this year was GE's kitchen hub. This control centre for the kitchen contains two cameras and a 27-inch touchscreen so you can play videos that walk you through a recipe in real time. And the hub will connect to other GE connected appliances such as the oven and washing machine, so you put a load of laundry on while you cook.

COOKING

Sous-vide is one of the best ways to cook food to perfection, but until now it's been expensive and reserved for chefs. Mellow is a smart sous-vide device that will be able to store food in a refrigerated state, weigh it and cook it ready for when you want it. It even has a smart chef that'll learn what foods you like to offer the perfect meal or make suggestions in the future.

HOT DRINKS

Smarter Coffee, as the name suggests, offers a clever way to make coffee via your smartphone and an app. Select what drink you want, how strong and for how many people; the machine will do the rest, and you'll be notified when it's ready to collect from the kitchen. If you want it for when you wake or arrive home, it can do that, too. More of a tea person? The iKettle heats water to particular temperatures to suit your chosen brew, while its Formula mode will boil water as soon as it hears your baby crying, then keeps it at the perfect temperature for bottles.

FOOD PREP

1986

All hail the microwave. While they were first introduced in 1967, it was in the 1980s that they became small and powerful enough to bear the load of cooking.

2016

Sous-vide is the new hassle-free cooker. Set the bagged food in the water-filled unit and it'll do the rest.

2036

Scientists are already showing off 3D printed food. By 2036, we may no longer grow food but will instead cultivate the right cells to print off our meals, and also print the plates we eat off.

FOOD MANAGEMENT

Never run low on food again thanks to Smart Fridge Cam and Smarter Mat. The camera sticks to the inside of your fridge door with suction pads and lets you look inside when you're out shopping. The Smarter Mat can be placed under items like milk in the fridge or rice in the cupboard, and will detect the weight to alert you when you're running low. And with the unstoppable rise of digital assistants like Siri, Alexa and Google Assistant, inevitably they've been integrated into kitchen devices – LG have just released an Alexa-enabled fridge (the InstaView ThinQ) and Samsung a Bixby-enabled one (the Family Hub 3.0).

GROWING

Growing fresh herbs no longer requires green fingers or even effort – the Smart Herb Garden automates it all. Just load in plant capsules, fill the tank with water and plug it in, and the Smart Soil and system's sensors will keep water, oxygen and nutrients at optimal levels for perfect growth. You just have to make sure it gets some light.

ILLUSTRATION: DANIEL BRIGHT

HOME OFFICE

HOLOGRAM-CONFERENCING

Videoconferencing lets you dial in to a meeting remotely. Some companies are now using telepresence robots with a tablet mounted on a moving base, letting you project your face on the screen while 'you' move around and interact with people. The next step could be holograms. TeleHuman 2 projects a 3D life-size image of someone in a remote location as if they were in the same room.

WI-FI

Wi-Fi once operated at frequencies of 2.5GHz, but now works at 5GHz for a slightly shorter range but higher bandwidth. Now it's gone the other way with HaLow, a low-power, long-range Wi-Fi. This is a bit like Bluetooth and will allow devices such as sensors and wearables to talk to each other without guzzling power. The result should be easily installable smart home upgrades with less reliance on mains power connections.

POWER

Wireless is the future, but even juicing up a smartphone via a charging plate will be old news soon. Companies are already showing off long-range, over-the-air power solutions. Energous WattUp claims to power devices from 4.5 metres away.

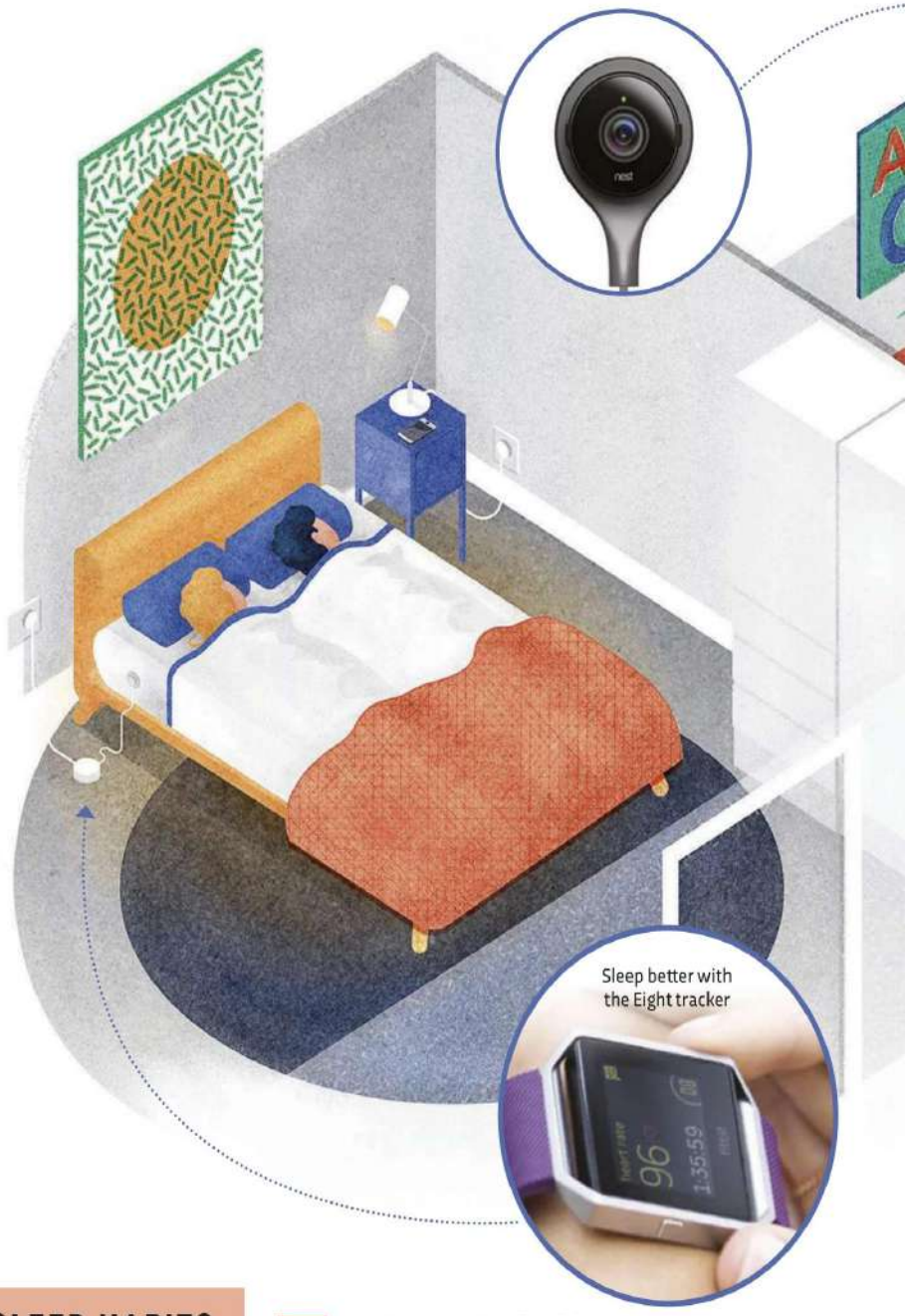
PRESENTING

Bye bye, PowerPoint. Hello, Samsung Flip – a 55-inch, 4K electronic whiteboard that connects to digital devices either wirelessly or via USB, then lets up to four users write, scribble or draw over the top.

PRINTING

Imagine raw materials being piped to your home, and a room-sized printer where nearly anything you can image can be printed. For now, fans of 3D printing can use sites like Thingiverse to create custom furnishings, but in the future, their repertoire could expand to include many more materials.


3D printers will soon be a standard part of the home


Sleep better with the Eight tracker

SLEEP HABITS

1986
Good sleep was attained from drinking a nightcap and shutting the curtains.

2016
Smart lights can gently ease a person off to the land of nod, while tracking tells them how well they've slept.

2036
Smart mattresses, clever lighting and noise-cancelling devices will create a perfect snoozing environment.

BEDROOM

SLEEP

A decent night's kip is something everyone would like, but at the moment sleep tracking is all that most people can hope for. But a new wave of smart mattresses and covers can not only track sleep, but help improve it too. The Eight is a cover that slips over your mattress. It tracks 15 factors and then warms or cools the bed accordingly to optimise comfort. Thanks to dual zones, Eight is able to track you and your partner's sleep individually, and improves as it learns.

STORAGE

With space at a premium, storage becomes an art form. Understairs cupboards that slide out

Smart mirrors let you catch up with the latest news while getting ready in the morning

THE LOO

1986

A basic porcelain toilet with a flush and perhaps a frilly toilet seat cover was all we could hope for.

2016

Now, in Japan at least, your toilet can sing to you, heat the seat, flush, open, close and even wash you automatically.

2036

Toilets will be able to harvest your waste for water and power. They'll probably be comfier too, which can't be difficult since we're still stuck on plastic seats right now.

Luke Edwards is a technology and gadgets writer.

BATHROOM

MIRROR

Other than your phone, the one place you look every morning is the bathroom mirror. Wouldn't it be nice for that mirror to have all your morning alerts from social media, news and email? Smart mirrors are touch-sensitive, and will display everything you need in one hub while you're brushing your teeth. They even contain cameras so you can virtually try on clothes.

SHOWER

The Nebia shower head 'atomises' water to create a cloud of smaller water droplets, which is more immersive than a regular shower. It saves 70 per cent on the amount of water needed and is 13 times more thermally efficient.

TOILET

Toilets are not just for waste – they are wasteful too. Bill Gates is throwing megabucks at cracking the problem of finding a perfect toilet. The solution should be one that saves water, increases recycled drinking water supplies, creates energy from human waste and is cheap to maintain. Good luck, Bill.

are currently a popular option. The future could be even more inventive. Imagine drawers that automatically vacuum-seal your clothes to save on space, or anti-gravity shelves that move up and down as needed.

FURNITURE

As some of the latest smartphones are port-free and charged wirelessly, it's time for furniture to catch up. Ikea sells tables and lamps with built-in wireless chargers, while Starbucks offers a similar feature on its tables. Simply drop your phone in the right spot and it'll juice up. Ease of use and reduced clutter make this a winner.

ILLUSTRATION: DANIEL BRIGHT

SMART CITY

More humans than ever before live in cities. Today, 54 per cent of us are urbanites. By 2050, that figure will rise to 66 per cent. And, by 2100, it will be 80 per cent. But all sorts of clever technologies are being introduced that will make city life stress-free, efficient and sustainable

WORDS: **JHENI OSMAN**

FLOWING TRAFFIC

Sensors on streetlights spot crashes and snarl-ups, alerting a central computer to coordinate traffic lights to keep you on the move.

SMART PARKING

Incredibly, up to 40 per cent of inner-city hold ups are caused by vehicles on the hunt for a parking space. Streetlight-based radars keep an eye on parking spots and relay availability in real-time to a smartphone app.

PEOPLE POWER

Public spaces harness 'people power' – the kinetic energy of pedestrians' footsteps is captured by floor tiles that convert motion into electricity. Sport pitch floodlights could even be powered by the players running around.

ENERGY BOOST

Buildings are clad in photovoltaic glass, which acts like a solar panel while letting light through. The next step is coating roads and cycle paths in solar panels.

POLLUTION SCRUBBERS

Instead of just marketing products, billboards also remove pollution from the air. In the presence of ultraviolet light from the Sun and water molecules from the air, titanium dioxide breaks down nitrogen oxides from car exhausts.

ROBOCOPS

Humanoid robots patrol the streets, acting as an eye on the streets and providing a point of contact with police call centres. Robocops are already active on the streets of Dubai. Meanwhile, some cities are trialling software that recognises individuals by matching their clothes, skin and hair, helping to spot troublemakers.

FREE PARKING

Parked electric cars help charge electric trains at peak times and get free parking in return. An intelligent system knows your commuting hours and ensures your car is fully charged on your return.

RUBBISH BUSTERS

Fed up of the stench of over-stuffed rubbish bins? Well, some cities are trialling bins fitted with sensors that alert the authorities when they are full.

DRONE PORTS

Making use of the redundant space on top of many city buildings, spaces to land drones ensure deliveries are on time. The company Skyports has created 15 such spots on roofs across London.

Jheni Osman is a science writer, author and presenter of *SciTech Voyager*.

POWER TOOLS
TO KEEP THE LIGHTS ON

After almost two centuries of us relying on fossil fuels, we're now seeing the damage they're causing to Earth. So what cutting-edge technologies might we use in the future?

WORDS: **DUNCAN GEERE**

The high-flying Buoyant Airborne Turbine captures more wind than traditional turbines

ALTAEROS

SKY-HIGH WIND TURBINES

Wind farms now account for 3.7 per cent of global electricity usage. And there's growing investment in offshore wind farms – £21.5bn was invested in 2016, 40 per cent up from the previous year.

But now that land and sea have been conquered, US engineers are looking to tackle the skies. Altaeros Energies is currently developing a device that will generate energy from the strong, steady winds hundreds of metres above the Earth's surface. It incorporates a three-blade horizontal axis wind turbine within an inflatable shell. When filled with helium, it floats into the air where it is held in place by tethers at a maximum height of 600m – so it won't spoil the view of the landscape.

At this altitude, the wind power density is three times that found at 120 metres, which is the typical height of an onshore wind turbine. The turbine features an autonomous control system that adjusts the device's direction and altitude to maximise its energy output. Electricity generated is transferred to a ground station by a connection in the tether. From here, it can be introduced to the grid or used to power equipment on site.

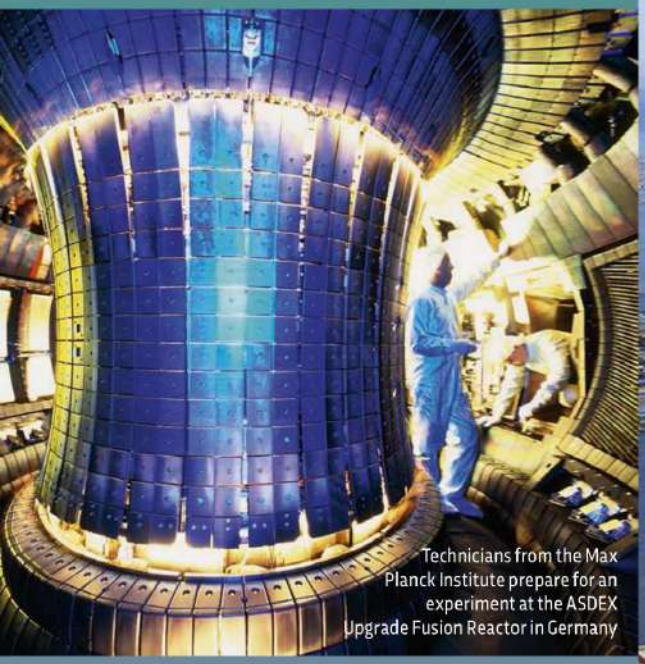
Altaeros is not the only player in the high-altitude wind game – a range of competitors with various ingenious technologies are also attempting to get their concepts off the ground.

Makani, which was acquired by Google in May 2013, has developed an 'Energy Kite' to capitalise on the wind resource at altitudes beyond the reach of conventional turbines. The kite is a tethered aerofoil that makes huge loops through the sky. As the wind rushes across the kite it rotates four mounted turbines. Meanwhile, Netherlands-based Ampyx Power is developing an auto-piloted glider that generates electricity as the tether fastening it to the ground station is extended.

POTENTIAL CO_2 REDUCTION BY 2050

ONSHORE WIND	84.6 gigatons
OFFSHORE WIND	15.2 gigatons
SOLAR FARMS	36.9 gigatons
WAVE AND TIDAL	9.2 gigatons
NUCLEAR	16.09 gigatons

SOURCE: Drawdown (Paul Hawken, Penguin, 2017)



Technicians from the Max Planck Institute prepare for an experiment at the ASDEX Upgrade Fusion Reactor in Germany

THE NEW NUCLEAR POWER

Nuclear energy has a bad reputation. Fission power plants – where uranium or plutonium atoms are blown apart – produce vast amounts of energy with near-zero carbon emissions. But they're expensive to build, produce dangerous waste and occasionally melt down with catastrophic consequences.

But there's another type of nuclear fission with none of those drawbacks. Safer and easier to fuel, thorium reactors have been possible for decades. The technology was sidelined during the Cold War, as it cannot easily produce the materials necessary for building nuclear weapons. But several countries are now building test reactors, with the first expected to be finished in India in 2018.

But the holy grail of energy production is nuclear fusion. While traditional nuclear power creates energy by splitting atoms, nuclear fusion smashes them together – which happens inside the Sun. The National Ignition Facility in California is forging the way, with another new facility being built in France. While small steps have been made, no-one has succeeded in conquering the ultimate challenge – to generate more energy than is required to start and maintain the reaction. If they can crack that, we'll have access to more clean, green energy than we can ever use.

FLOATING SOLAR FARMS

There has been a recent drive to site solar farms in more adventurous locations to make the most of the formidable clean energy resource that is offered to us by the Sun's rays. Solar panels started on the rooftops and then expanded into fields, but now developers are experimenting with constructing them on water. In September 2014, the UK's first floating solar array was built on a reservoir located on a Berkshire farm. The 200kW solar panel system will reduce the farm's energy bills as well as slash its carbon emissions.

In the UK, floating solar is attractive because it avoids the criticism levelled at land-based projects that take up valuable agricultural real estate. The opportunity offered by floating solar is especially appealing in countries where land availability is at a premium. Indeed, Japanese electronics manufacturer Kyocera recently announced plans to build the world's largest floating solar power plant of 11,000 PV panels over two lakes. The sites would generate 2.9MW of electricity – enough to serve the requirements of nearly 1,000 homes.

With 11,000 PV panels, the proposed solar power plant in Japan would be the world's largest

In Gothenburg, Sweden, there is a 1,000km district heating network, where rubbish is burned to heat more than 90 per cent of all apartment blocks in the area

The Eco Wave Power convertors draw energy from the waves via their uniquely shaped floaters, which rise and fall with the up and down motion

BBC RADIO 4

Listen to an episode of *Analysis*, which asks whether we can live without nuclear power, at *bbc.in/1GclAmK*

RUBBISH POWER

Many communities in Nordic countries burn rubbish for heat and energy. With this system, Sweden achieves a 99 per cent recycling rate, even going as far as to buy rubbish from neighbouring countries to fuel its combined heat-and-power stations. In some cases, these plants have an 80 per cent efficiency, meaning that far less fuel is consumed to produce the same amount of useful energy than traditional power stations. It works across a range of scales, too, from incinerators connected to massive networks of hot-water pipes that power and heat entire cities, to smaller systems that heat a single building and provide electricity. Manhattan's steam system is still used to heat 100,000 buildings, while a few other US towns are using or planning to install similar systems.

OCEAN ENERGY

The oceans cover more than 70 per cent of the Earth's surface – and are a rich energy resource. According to a 2001 World Energy Council survey, the energy potential of coastal tides is over 450 gigawatts and could provide up to 25 per cent of US electricity needs. With its extensive coastline, the UK is perfect for developing tidal power – although plans to build the world's first tidal power lagoon in Swansea Bay have just been thrown out by the government.

Meanwhile, waves could provide up to half of all our energy needs. Rather than tether a wave machine to the ocean floor at huge cost, Eco Wave Power has designed a system of buoys and generators to attach to structures that already exist, such as docks.

The depths of the ocean also hold potential. Ocean thermal energy conversion (OTEC) exploits the temperature difference between the deep cold depths and the warmer surface. There's currently an experimental OTEC plant in Hawaii, but other systems are in development around the globe.

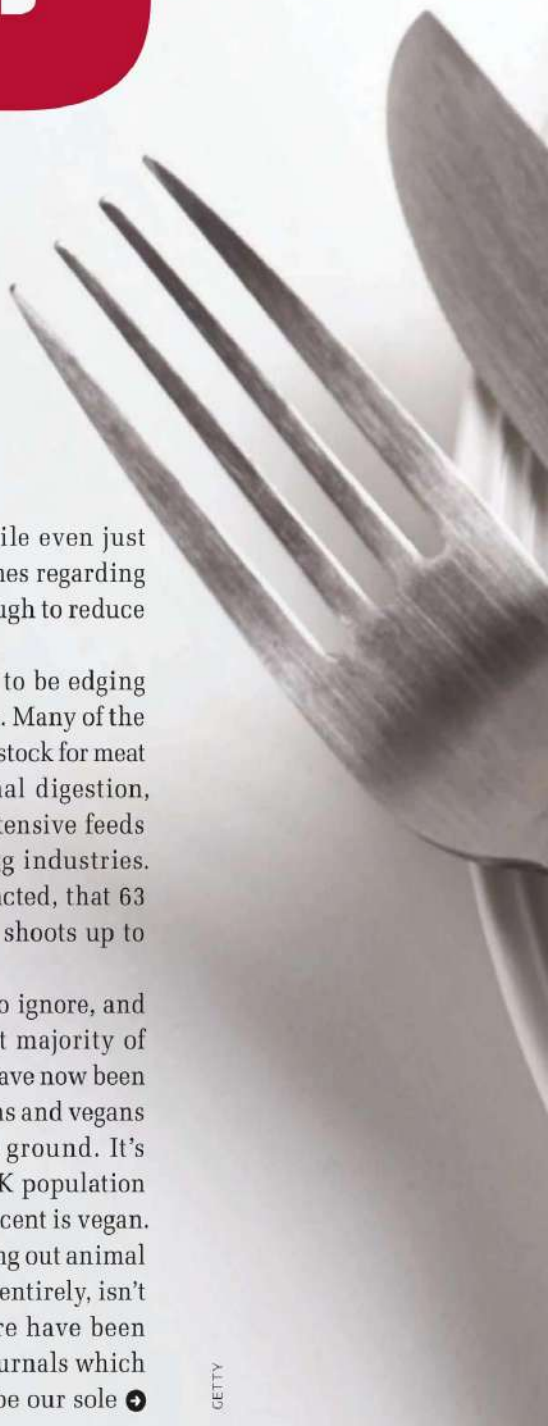
Duncan Geere is a technology writer.

GETTY, KYOCERA, GOTEBORG ENERGI, ECO WAVE POWER LTD

THE FUTURE OF FOOD

The never-ending deluge of information about our food choices can be baffling. What will we be eating in the future? Will we all become vegan? Or are there other alternatives so that we can have our steak and eat it?

WORDS: **TOM IRELAND, JOSH GABBATISS** AND **JV CHAMARY**



GETTY

Diet can be a contentious issue, subject to the forces of personal ethics, religious beliefs and health concerns. In recent years, scientists and the public have become increasingly aware that the food we eat can have negative impacts on the planet.

According to figures from the Consultative Group on International Agricultural Research (CGIAR), one-third of our greenhouse gas emissions come from agriculture. But that's just one factor. Our food system is also the leading cause of deforestation, land use change and biodiversity loss in the world. Then there's overfishing, pollution, groundwater depletion, excessive fertiliser use and pesticides to contend with as well. With all these issues to consider, a 'sustainable' diet might mean different things depending on who you talk to. However, certain trends cut through the noise – most notably, an emphasis on more plant-based diets. A paper published in 2016 in *Proceedings Of The National Academy Of Sciences* concluded that a mass switch to vegetarianism would bring down food-related greenhouse gas emissions by a whopping 63 per cent, while even just sticking to global health guidelines regarding meat consumption would be enough to reduce emissions by 29 per cent.

As for veganism, it does seem to be edging ahead in the planet-saving stakes. Many of the issues that arise from farming livestock for meat – methane emissions from animal digestion, pollution from farms, energy-intensive feeds – also apply to the dairy and egg industries. If widespread veganism was enacted, that 63 per cent reduction in emissions shoots up to 70 per cent.

These seem like hard figures to ignore, and yet ignored they are by the vast majority of people. While plant-based diets have now been normalised, practising vegetarians and vegans are still relatively thin on the ground. It's thought only 2 per cent of the UK population is vegetarian, and less than 1 per cent is vegan.

But stop the press! Maybe cutting out animal products entirely, or even nearly entirely, isn't necessarily the way to go. There have been studies published in reputable journals which suggest that vegetables may not be our sole


NORTH AMERICA
ATLANTIC OCEAN
SOUTH AMERICA

While plant-based diets have now been normalised, vegetarians and vegans are still relatively thin on the ground

salvation. Back in 2015, a particular paper caused a media firestorm when its lead author, Prof Paul Fischbeck of Carnegie Mellon University, made the declaration that "eating lettuce is over three times worse in greenhouse gas emissions than eating bacon". "LETTUCE WORSE THAN BACON" screamed the headlines, as commentators smugly observed that vegetarianism isn't all it's cracked up to be.

Other research has suggested that at least some degree of carnivory could be beneficial. A recent analysis of 10 distinct diets, each with a different ratio of meat and animal products, saw veganism relegated to fifth position when it came to maximising sustainable land use, below different degrees of vegetarianism and omnivory. This comes as a blow to vegans who tend to assume, understandably, that due to the well-documented problems with livestock farming, their diet plan automatically places them in the top spot.

How can researchers come to such different conclusions? Well, the short answer is because they're trying to answer a complicated question. To work out the best diet for the planet, scientists tally up the environmental costs of the production, transportation and marketing of foods, and then compare the options. Yet there are many such costs involved, and therefore many potential metrics. Some researchers completely ignore certain aspects, such as the amount of food that is wasted, while others place more emphasis on aspects that they deem to be most relevant.

For example, there is no question that red meat produces far more emissions than vegetable protein sources like lentils and beans – around 13 times more, in fact. But if you're focusing on land use, then cows and sheep start to make a lot of sense. Livestock, and food for livestock, can be farmed on land that's unsuitable for human crops, so if that land can be put to good use it will improve the efficiency of food production in a given area.

As for the idea that lettuce is worse for the environment than bacon, the researchers had opted to analyse emissions on a per calorie basis. This is an unfair comparison. After all, no one is suggesting that vegetarians replace two rashers of bacon at breakfast with the 3.3kg of lettuce it would take to match them, calorie-wise. But what Fischbeck and his colleagues wanted to emphasise was the need to consider foods on their individual merit, rather than assuming that just because you have chosen diet A or diet B, you are automatically saving the world.

VARIETY IS THE SPICE OF LIFE

This is a good point. There is an awful lot of variety in green credentials, even within food groups. Beef and lamb produce far more emissions than pork, which in turn produces more than chicken. As for fish, the variation in impact is enormous, so diverse are the means by which different species are caught or farmed and the levels of threat they are all under in different parts of the world.

Fruits and vegetables are even more complicated. Robust produce that can be grown in fields, such as cabbage and potatoes, result in relatively low greenhouse gas production, but if a plant requires intense refrigeration, or has to be grown in a hot house, alarm bells begin to ring. Similarly, vegetables which must be flown great distances before they arrive on your plate come with a sizeable emissions price tag. That's before you even consider the huge quantities of water needed to grow citrus fruits, or the pesticides that are pumped into banana plantations. Greenhouse gases, though the most widely used measure of impact, only tell one side of a far more complicated story, and those who opt for more plant-based diets must be wary of replacing the animal parts of their diet with plants that cause harm in other ways.

RIGHT: Red meats, like beef and lamb, have a greater impact on the planet than chicken

BELOW: People who follow vegetarian diets should still be aware of how their favourite foods affect the planet

GETTY X2

FACTS TO CHEW OVER

Is the amount global meat consumption is forecast to rise by 2050, due to growing incomes and urbanisation in developing countries.

9.7 billion

The estimated population of Earth in 2050. Growing enough food to feed a rapidly increasing global population is already a pressing concern.

15,000 litres

The water required to make 1kg of (farmed) beef, compared to 2,500 litres for 1kg of rice.

7.1 trillion kg

The CO_2 equivalent contribution of global livestock farming per year. This represents 14.5 per cent of all anthropogenic greenhouse gas emissions.

The proportion of people who said they wanted to try cultured beef following the presentation of the world's first lab-grown burger.

Agroecology involves working with nature and putting control back in the hands of small-scale farmers

The fact is, whichever label you choose to define yourself – vegan, vegetarian, pescetarian or omnivore – there's no room for complacency. Ultimately, the choices you make about your food are just as important as the diet tribe you belong to.

The choices you make about your food are just as important as the diet tribe you belong to

FUTURE FARMING

Another layer of complexity is the variety of farming strategies in use. Rather than demonising meat, some argue, policies could ensure that livestock farming is more efficient and produces fewer greenhouse gases. This may sound a little too good to be true, but scientists have suggested that by simply supplementing the grazing diets of cattle and sheep with higher quality feeds, emissions from livestock farming could be reduced by nearly a quarter in the next two decades.

So relatively simple changes can make a difference, but when considering the scale of our food system's impact on the planet, something bigger might be necessary. Industrial agriculture has been our go-to system for some time, but the overuse of powerful chemical pesticides and fertilisers is resulting in degraded ecosystems that are ultimately unsustainable.

The solution to this could be agroecology, which operates under the mantra of 'working with nature, rather than against it', restoring biodiversity and ecosystem functions in order to ensure productivity. These principles are already being put into action. As it stands, rice accounts for up to a third of our annual water use, but a low-water agroecological method known as System of Rice Intensification (SRI) is increasingly being used to produce rice yields

BBC TWO
Watch clips from *The Secrets of Your Food*
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up to 50 per cent larger. Water is only applied to the rice when needed, compost is used instead of chemical fertilisers, and farmers weed by hand, instead of using herbicides. Using this method, Sumant Kumar, a farmer from the Indian state of Tamil Nadu, has smashed the previous annual rice-growing record by an astonishing three tonnes. Whether it involves rice, pigs, fish or apples, agroecology is about dismantling the current system and placing power into the hands of small-scale producers and family farms. If this is starting to sound a bit too 'eco-warrior' for your taste, it's worth noting that the UN is behind this trend.

A truly environmentally friendly diet relies on major systemic changes, but individual diets also need to change. The variety of data on offer can give the impression of flip-flopping within the scientific community, but it's more indicative of the sheer complexity of the subject – not to mention the competing interests of stakeholders in the food industry. In fact, certain trends are clear.

With the abundance of foods available to people in the western world, one meat-free day a week should be easy to achieve

Headlines about the evils of lettuce and veganism saving the world may seem misleading, but it would be disingenuous to pretend that farming animals isn't a problem. People in the West are eating too much meat, and as countries like China and India become wealthier, their demand for it is increasing. Dr Rajendra Pachauri, ex-chairman of the UN's Intergovernmental Panel on Climate Change called for one meat-free day a week as a way of personally making a difference, and this seems like a good place to start. Other sensible suggestions include choosing fish from sustainable or certified stocks, buying vegetables that store well, and avoiding food waste. The kind of mass switch to veganism envisaged by some studies is probably unrealistic, but relatively small changes in the way we eat can produce sizeable effects. While we may not have all the information, we certainly have enough to make a difference.

Josh Gabbatiss is a science writer based in London.

Tom Ireland is a science writer and managing editor at the Royal Society of Biology.

JV Chamary is the author of *50 Biology Ideas You Really Need To Know.*

GETTY X2

TOMORROW'S

Synthetic milk

Perfect Day (previously known as Muufri – pronounced 'moo-free') is one of the companies developing cow-free milk. Milk-producing genes are inserted into yeast, which are then bred in vast numbers to produce milk proteins. The company, based in Cork, has just raised €20.9m to try to get its synthetic milk to market.

Appetising algae

Seaweed grows quickly and is a core part of Japanese diets. As it can be grown at sea, it would solve the issue of dwindling land for crops. There are thousands of varieties that could be farmed and eaten.

Downloadable dishes

3D printing is already used to create fancy structures in high-end sweet-making, and to speed up the process in commercial kitchens and bakeries. If 3D printers continue to advance, people will be able to download a recipe and 'print' their own meals in the comfort of their own homes. The question is: will it taste as good if you haven't spent hours slaving over a hot stove?

Artificial meat

Back in 2013, the world watched as food critics tucked into the first ever lab-grown burger. The small pink patty, prised out of a petri dish and fried in front of the media, was proof that it was possible to grow safe and edible meat without slaughtering a single animal. There was just one problem: the patty had taken two years and over $300,000 (£226,400) to produce.

Fast forward a few years and costs have plummeted. One company who makes artificial meat – Memphis Meats – says it costs $2,400 to produce, due to the pricey medium needed to culture cells. But the company aims to reduce that cost to under $5. The key is scaling up the technology to the level of an industrial food process.

Polls suggest there's a willingness to give this modern meat a go. A survey by *The Guardian* found that 68 per cent of people wanted to try cultured meat. But whether people reach for cultured burgers at the supermarket is a different matter entirely.

Reptiles

Turtles and terrapins, crocs, snakes and lizards are a key source of protein in many parts of the world. Turtle soup, once a European delicacy, is still eaten in the Far East and elsewhere, and is made from the meat or plastron (shell on the underside), while consumption of crocodile and alligator meat is often a by-product of the leather industry. According to a 2009 paper on the biological risks of eating reptiles in the *International Journal of Food Microbiology*, they can be hazardous to health if not properly prepared. So cooking croc and friends might not take off in this country.

FOOD

What else could be on your plate in the future?

Insects

Most of the developing world already indulges in entomophagy – consuming edible insects. It's being considered as an alternative to meat by the UN, which is chewing over the idea that insects are easier to raise than livestock and produce less waste. Insects are cold-blooded so they don't consume energy (and need food) to maintain body temperature: 1kg of feed only yields 100g of beef, but up to 600g of insect meat. Insects could be added subtly, such as dry-roasted to replace nuts in cookies. It's likely that consumers will start finding ingredients such as flour made from crushed crickets in their food.

GM foods

Plants can be genetically modified by inserting specific genes into a cell or 'switching off' certain genes that already exist. This means, for example, that a field can be sprayed with weedkiller and the GM crops will be unaffected. Or a gene that controls tolerance to stress can be turned off to produce better yields under environmentally stressful conditions.

GM food ignites heated debate. We have the somewhat contradictory situation in Europe that only a tiny area of farmland is used for cultivating GM crops, yet about 90 per cent of imported soybeans come from GM sources. This means that people in the EU indirectly consume a large amount of GM because many animals eat imported GM feed. Meat, milk and eggs from animals fed on these products are sold throughout the UK, but do not need to be labelled as GM.

Indeed, the Royal Society states there is no evidence that a crop is dangerous to eat just because it is GM. So, in future, maybe we will find ourselves eating more GM food.

Fungi

No, not mushrooms – mycoprotein. You'll probably recognise the brand Quorn, named after a Leicestershire village. Quorn is made by growing the filamentous fungus (mould) *Fusarium venenatum* in fermentation tanks. The mycoprotein used to be marketed as 'mushroom protein' until manufacturers were told to stop by the Advertising Standards Agency. It's now described as a "member of the fungi family". Earlier this year, a report claimed Quorn worldwide sales increased by 16 per cent last year (and 25 per cent in the US) and is set to become a billion-dollar business in the future.

GETTY X10

Wheat gluten

Also known as wheat-meat, seitan or mock duck, wheat gluten is made from the 'glue' of wheat. As well as having a higher protein content than more well-known meat substitutes such as tofu (soya bean curd), wheat gluten's chewy consistency also gives it a meaty texture. The food is thought to have been first produced by Buddhist monks who adhere to strict vegetarian diets, and it's particularly popular in Asian cuisine. Although wheat gluten tastes bland on its own, it's good at absorbing flavours from marinades and sauces.

Dodo kebabs

With progress in tissue engineering and gene-editing (such as the precise CRISPR technique), it may be possible to combine characteristics of different animals into entirely new meats, or even produce the flesh of extinct animals in the lab.

BIG TECH TRENDS

Prepare yourself for tomorrow with these cutting-edge innovations

VIRTUAL REALITY GETS REAL

After years of hints and speculation, augmented reality start-up Magic Leap, valued at close to $2bn (approximately £1.5bn), finally unveiled its first headset at the CES tech show earlier this year.

The Magic Leap One system consists of a pair of goggles, a miniaturised PC worn on a belt and a handheld controller. Its creators say the device makes use of lightfield technology, which records a map of how light reaches a camera lens. With this information, the Magic Leap team says it can convincingly mix the virtual with the real. For example, while wearing the goggles, animated characters could spring out of your favourite novel or a computer display could be made to appear on your fridge door. There's still no word as to when the Magic Leap kits might go on sale, but Magic One says it expects to start shipping this year, so they can't be too far off.

There were plenty of other virtual and augmented reality headsets at CES, including the Vive Pro from HTC (with a much higher-res display than the existing Vive); the eye-tracking, EEG-equipped Looxid VR; the affordable, fold-out Aryzon; the Alexa-enabled Vuzix system; and the X1 headset from Third Eye. Depending on how cynical you are, this either means that human communication and interaction is about to end, or that Pokémon Go is about to get a bit more convincing...

MAGIC LEAP

The Magic Leap goggles. The system claims to merge reality with the virtual world

CLEVER CRYPTOCURRENCIES

Accepted by multinationals and assassins alike, crytocurrencies are everywhere. From Bitcoin, Litecoin and Ethereum to newcomers like Zcash and Ubiq, there are over 1,000 different varieties to trade in.

At the heart of most cryptocurrencies is the electronic ledger, blockchain, which keeps a permanent and unalterable record of every transaction ever made. It's this that prevents people creating counterfeit Bitcoins. The whereabouts of every genuine transaction is updated on the blockchain, along with a version of the same information that's been mathematically transformed – 'hashed' – in a way that produces a radically different outcome if the information is tampered with. Any attempt to amend a transaction will produce a mismatch that's instantly spotted. For added security, the hashed version of each transaction also depends on parts of the previous transaction, plus some extra ingredients.

Traditional banks are looking into using cryptocurrencies for verifying electronic transactions, while hospitals and energy companies are eyeing its use for databases. Long story short: with cryptocurrencies combining with card and contactless payments, cold, hard cash, in its physical form, may not be king for much longer.

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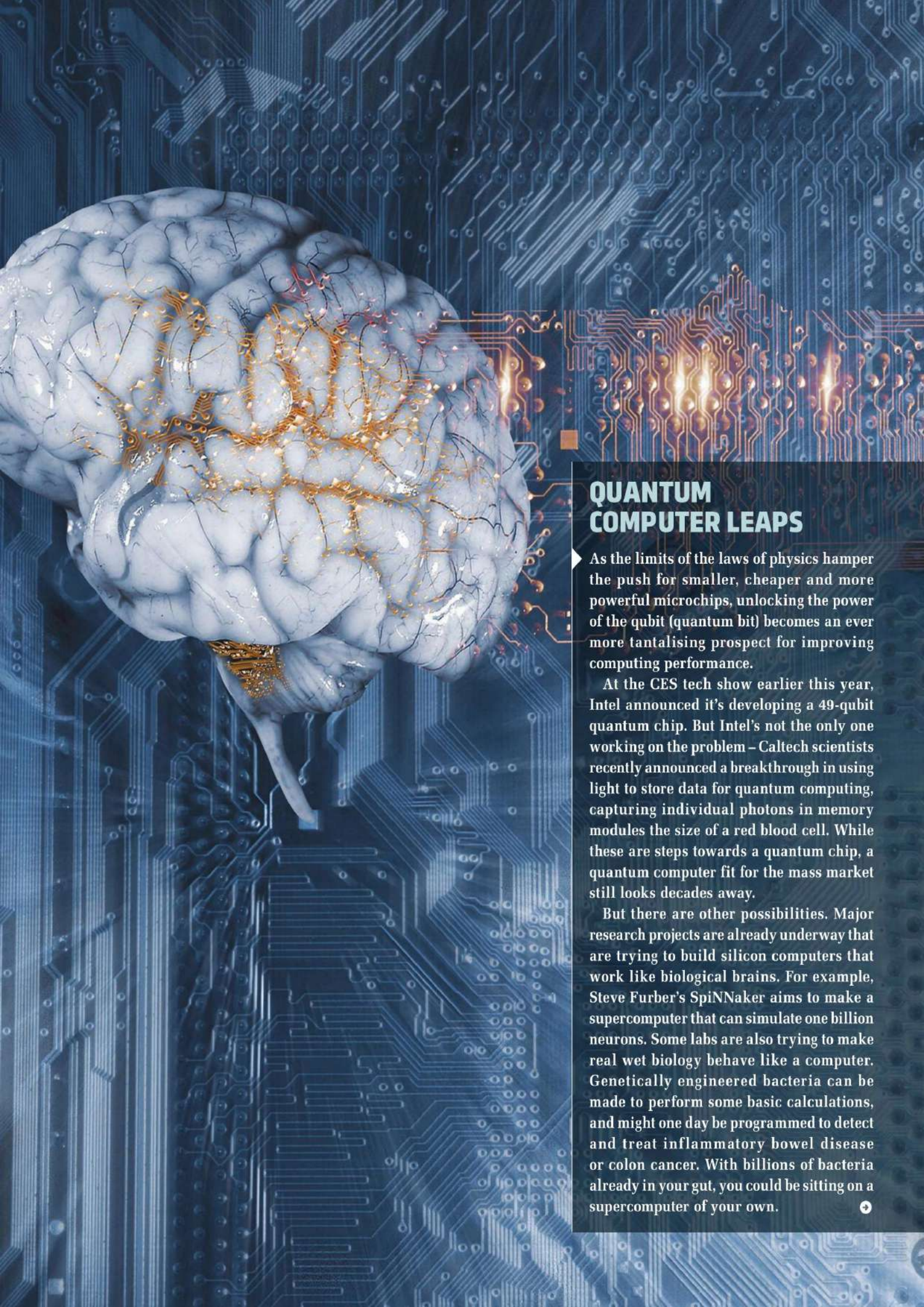

QUANTUM COMPUTER LEAPS

As the limits of the laws of physics hamper the push for smaller, cheaper and more powerful microchips, unlocking the power of the qubit (quantum bit) becomes an ever more tantalising prospect for improving computing performance.

At the CES tech show earlier this year, Intel announced it's developing a 49-qubit quantum chip. But Intel's not the only one working on the problem – Caltech scientists recently announced a breakthrough in using light to store data for quantum computing, capturing individual photons in memory modules the size of a red blood cell. While these are steps towards a quantum chip, a quantum computer fit for the mass market still looks decades away.

But there are other possibilities. Major research projects are already underway that are trying to build silicon computers that work like biological brains. For example, Steve Furber's SpiNNaker aims to make a supercomputer that can simulate one billion neurons. Some labs are also trying to make real wet biology behave like a computer. Genetically engineered bacteria can be made to perform some basic calculations, and might one day be programmed to detect and treat inflammatory bowel disease or colon cancer. With billions of bacteria already in your gut, you could be sitting on a supercomputer of your own.

Stick this sensor on a nail and stay safe in the sun

This robot suitcase, called Gita, navigates using a series of cameras attached to the bot's body

HOLIDAY HELP

Airports can be stressful. This cool hands-free robot suitcase will save you lugging your bags around. Developed by a spinoff of Piaggio (who make the stylish Vespa mopeds), the two-wheeler follows you around and can carry up to 20kg.

When you get to your destination, smart-glasses like the Vuzix Blade will help you find your way and translate signs.

Once on the beach, if you're worried about your exposure to UV rays, then you can stay sun smart with a tiny sensor from L'Oréal that sits discreetly on your thumbnail. It uses an NFC connection to relay data on your UV exposure to an Android/iOS app, warning you when it's time to get out of the sunshine.

So what's next? A robot to save you a spot by the pool?

BBC RADIO 4

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SMARTER SMARTPHONES

Smartphones are about to get smarter. Vivo has just developed the first-ever in-screen fingerprint scanner, which means you simply press your index finger on the screen where the home button would normally be. Other cool tech changing the smartphone market includes double wireless charging speeds, phones being used as trackpads for laptops and AI-integrated devices. So what does the far future hold? Well, our guess is we won't have smartphones as separate devices at all, instead we'll have gadgets integrated into our heads and hands.

The Halo Sport claims to not only play your favourite tunes, but also stimulate your little grey cells

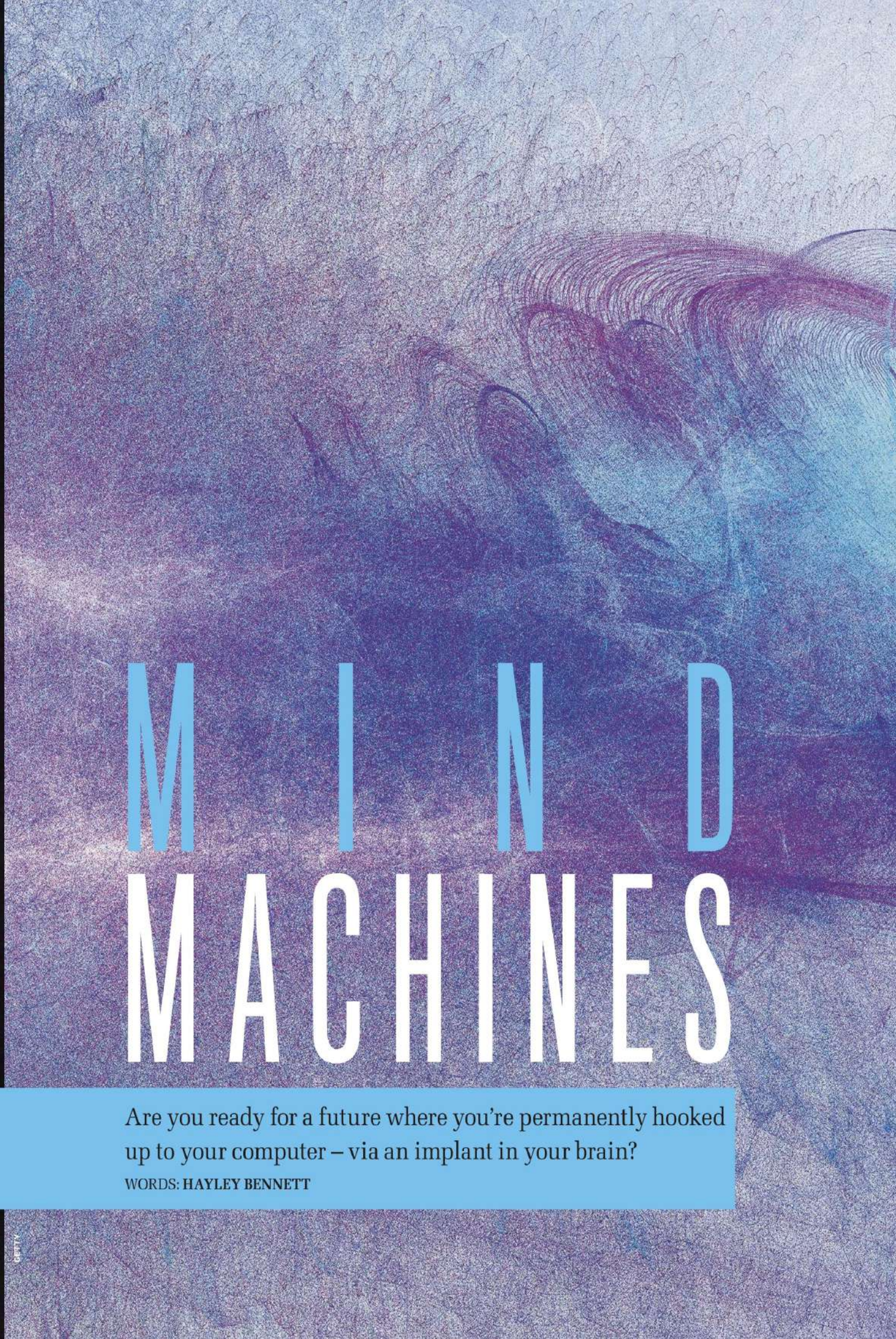
KEEPING FIT

Gadgets have flooded the fitness arena in recent years. So much so in fact that you'd be forgiven for thinking you can't go for a simple swim, ride or run without monitoring your heart rate, counting your steps and charting your route, speed and distance. And that's without even mentioning sleep trackers...

Fitness trackers in all their many forms are probably here to stay for a good few years yet, but one thing that's changing is their appearance. The rubbery wristbands and bulky bangles that typify current fitness trackers are giving way to slimmer, more subtle designs that look more like everyday watches. Good news for anyone who wants to keep an eye on their activity without looking like an off-duty Power Ranger.

Tech can help if you're looking to develop skills as well as your fitness, say if you're working on your backhand volley. The Halo Sport device may look like a normal set of headphones, but as well as playing music it's also stimulating the neurons in your motor cortex that tell which muscles to fire and in what sequence. The electrical signals it emits are said to promote the neuroplasticity required to help you learn new skills and fine-tune your ability to perform them.

What if you could do more than just keep fit when you're keeping fit. Well, a team at Binghamton University have created a fabric-based, bacteria-powered bio-battery. The fuel cells use *Pseudomonas aeruginosa*, a small rod-shaped bacterium, along with a pair of electrodes coupled with a silver and silver oxide solution to produce electricity. The fuel cells were able to generate electricity in a stable manner, even when subjected to the stretching and twisting exhibited over a long lifetime. According to the team, the microbial fuel cells could produce more electricity than previous textile biobattery designs. So when you're out jogging in years to come, you could conceivably be juicing up your smartphone while you're getting a sweat on.



MIND MACHINES

Are you ready for a future where you're permanently hooked up to your computer – via an implant in your brain?

WORDS: **HAYLEY BENNETT**

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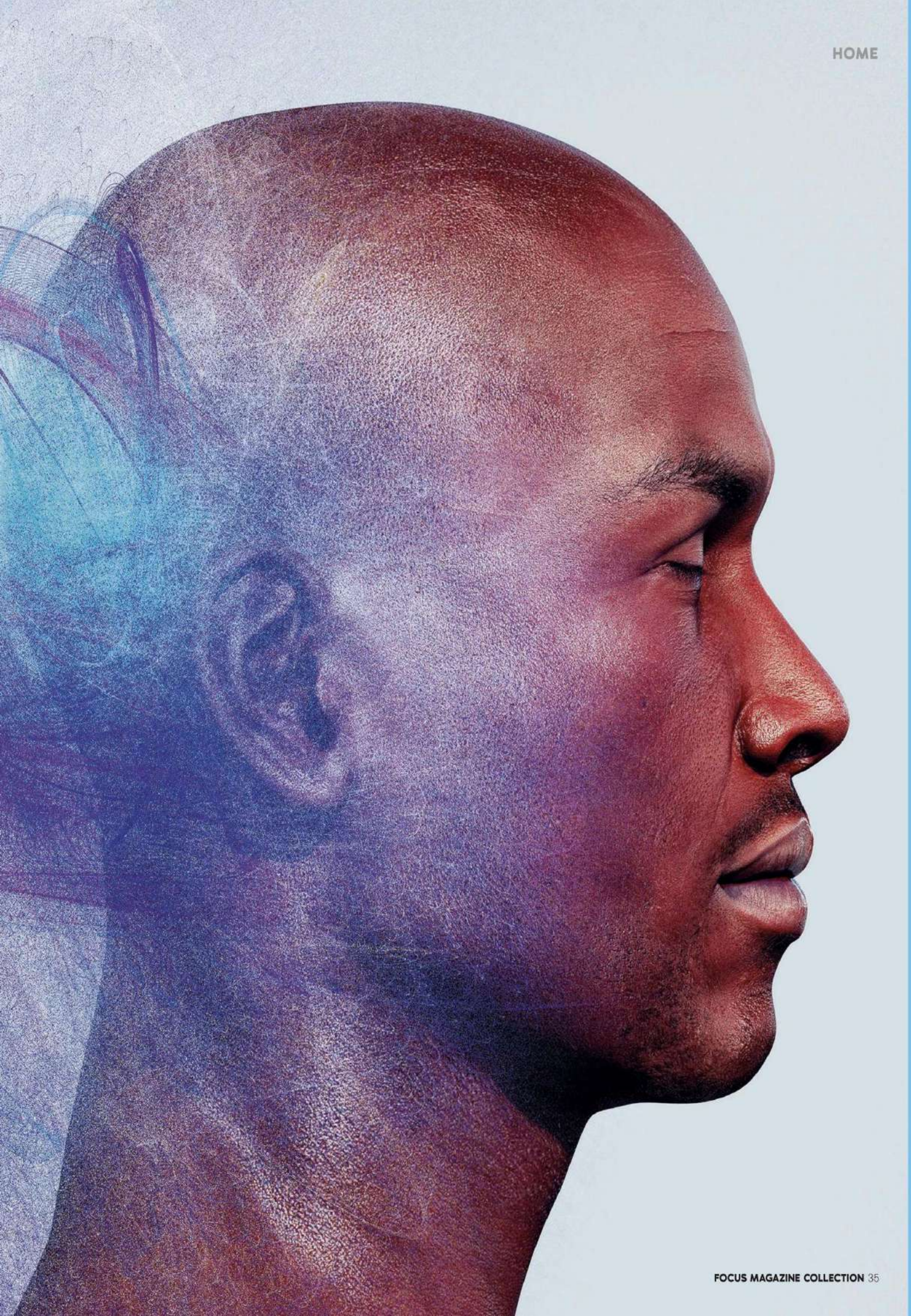


You get back from work, crash out on the sofa and pick a track from your favourite playlist. Without moving from that spot you start heating up the oven to cook dinner before beginning a conversation with your friend who lives on the other side of town. You do all this without ever saying a word or pressing a single button. How did anyone get anything done before brain interfaces?

The idea that we could run our lives from inside our heads is, obviously, a fantasy, but there are those who are attempting to make it a reality. In 2017, SpaceX and Tesla billionaire Elon Musk announced a new venture, Neuralink. Its aim: to build a high-bandwidth, implantable brain-computer interface that will enable us to be permanently online and allow us to communicate wirelessly with anything that has a computer chip. The device could, theoretically, let us have thought conversations with our friends, share memories as if they were smartphone videos and 'know' anything we wanted by simply calling it down from the cloud.

Meanwhile, earlier this year, the US Defense Advanced Research Projects Agency (DARPA), also announced plans to develop next-gen brain-computer interfaces, with the aim of enhancing the abilities of military personnel. A recently released document suggested a possible experiment for testing these devices: "a human subject controlling multiple drones in a virtual reality set-up, while receiving sensory feedback to portray the status of each drone." So, we might one day see soldiers controlling drones with their minds.

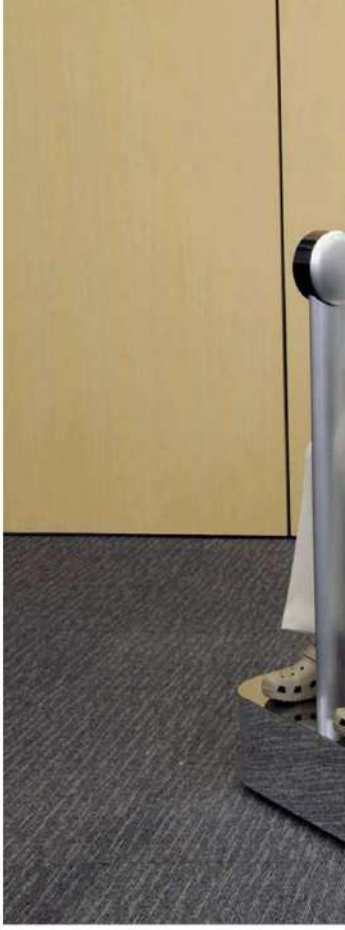
It certainly sounds impressive, but is it really possible? Primitive versions of brain-machine interfaces have already been used to help paralysed people move prosthetic limbs, but could we really see this technology making the leap to everyday use?

A brain-computer interface is a device that's able to read the electrical impulses coming from the brain's nerve cells (neurons) using electrodes and ideally also write to the brain, delivering information to the user by stimulating groups of neurons. Neuralink's ultimate goal is to build an interface that interacts directly with each of the 86 billion neurons in our brains, and the company is apparently in the process of putting together a crack science team for its project. The finer details of exactly how Neuralink plans to do this remain under wraps, however.

"I'm still looking for more information on this," says Dr Davide Valeriani, who studies brain-computer interfaces at the University of Essex. "Musk has announced these initiatives and then for a while hasn't said anything else."

Valeriani works with the kind of brain-computer interfaces that you might be familiar with – electroencephalography (EEG) caps, those ugly skullcaps with all the sensors and wires attached to them. "You can imagine this as a system you can put in a backpack, with electrodes integrated into something we wear already, such as a hat," says Valeriani. All it takes to get this system working for a particular user is half an hour or so of training, not for the human but for the machine, which has to learn which patterns in the person's brain are associated with certain thoughts.

Valeriani uses these EEG set-ups for group decision-making tasks. In one experiment from a 2017 study, his team asked groups of people wearing the caps to look at pictures of penguins and try to spot a polar bear in each image. Electrodes in the EEG caps monitored their thought responses – whether there was or wasn't a polar bear – and a computer delivered their collective answer. Perhaps it's not too much of a stretch to imagine using the



ABOVE: Back in 2009, the Honda Research Institute demonstrated a helmet that allowed a user to control an ASIMO robot by thought alone. Yes, it looked a little clunky, but it represented a ginormous leap forwards in technology

RIGHT: This exoskeleton was modified to include a brain-machine interface that allowed Juliano Pinto, a young paraplegic, to make the symbolic first kick at the 2014 World Cup

LEFT: Neurable's brain-computer interface replaces the headstrap of a VR headset with electrodes that read brain activity, so users can control VR games with their mind

Primitive versions of brain-machine interfaces have already been used to help paralysed people move prosthetic limbs

same technology to set up a work meeting or agree on a lunch date with friends – the only downside would be having to spend every waking moment wearing an EEG hairnet hooked up to a tangle of electronics in your backpack.

PLUGGED IN

The alternative is having the electrodes implanted directly in your head, which is what Matthew Nagle did in 2004. Clinical trials of implantable brain-computer interfaces have so far been mostly focused on paralysed people, because for them, the gain in function is worth the surgery and its risks. A quadriplegic, Nagle took the opportunity of a trial to get hooked up to a computer, allowing him, after some practice, to control a cursor on a computer screen with his mind, operate a TV and send emails. Last year, researchers used an updated version of this implanted 'Braingate' interface to give three paralysed people the ability to type up to eight words per minute with their brains.

Unfortunately, the current state-of-art for this system requires roughly 100 electrodes and a thick set of cables to be plugged in directly through the top of your skull, risking infection and resembling something out of *The Matrix*. "That's one of the major issues," says Prof Dr Thomas Stieglitz, who's developing brain-computer interfaces for medical applications at the University of Freiburg in Germany. "There are still these ugly connectors that are screwed into the skull and poke through the skin." Scaling up to a whole-brain interface – à la Neuralink – would require millions or billions more electrodes, which currently can't be detached from their connectors.

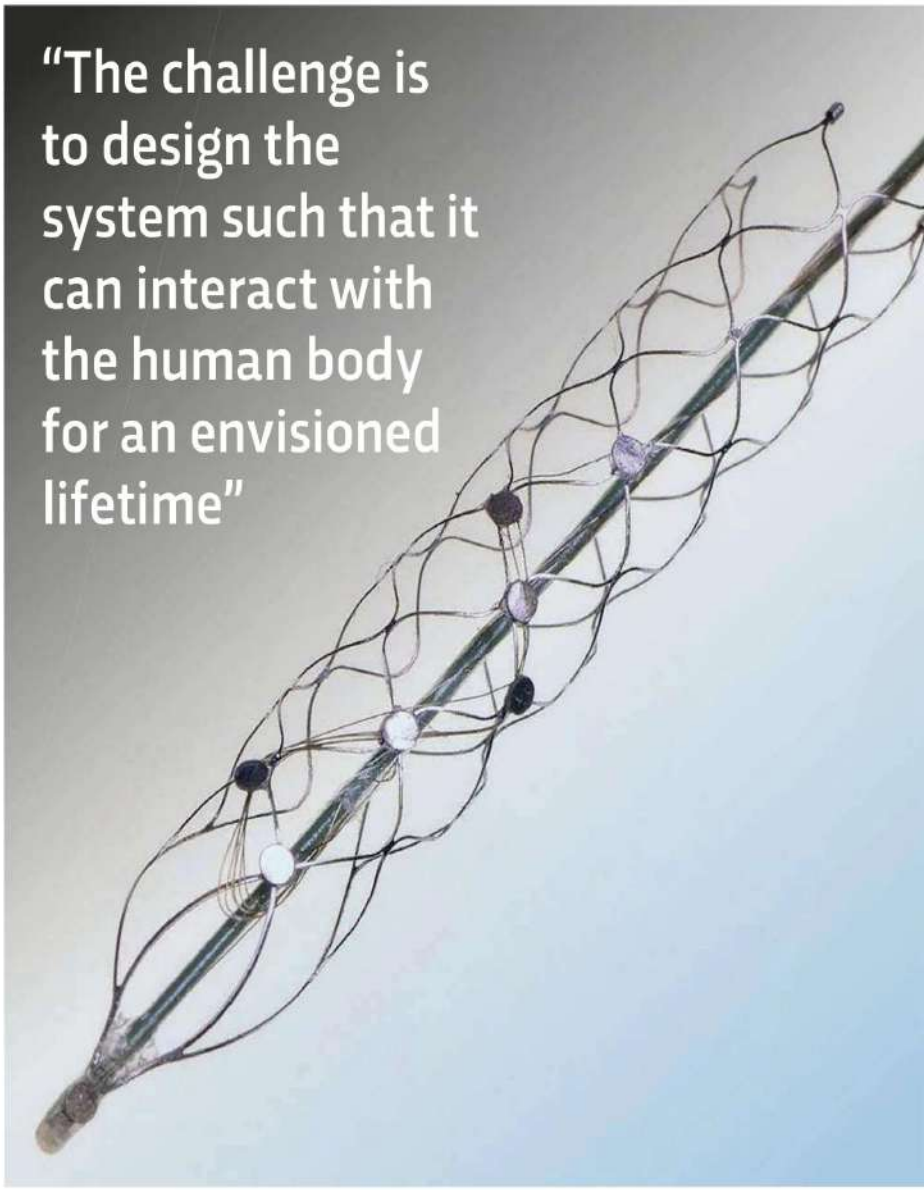
In Freiburg, Stieglitz's team is trying to build an implant that can suppress the brain signals leading to an epileptic seizure – a step, perhaps, towards widespread use of brain-computer interfaces for the more able-bodied. "Our dream," he says, "would be that the implant has a program that says 'Okay, this seems to be a seizure event in six seconds and I know that I should stimulate this part of the brain to interrupt the seizure.'" In fact, he adds, there's already one implantable device, a neurostimulator from the company NeuroPace, that's approved as a medical product for this purpose. Meanwhile, University of Freiburg spin-off company Neuroloop is ➔

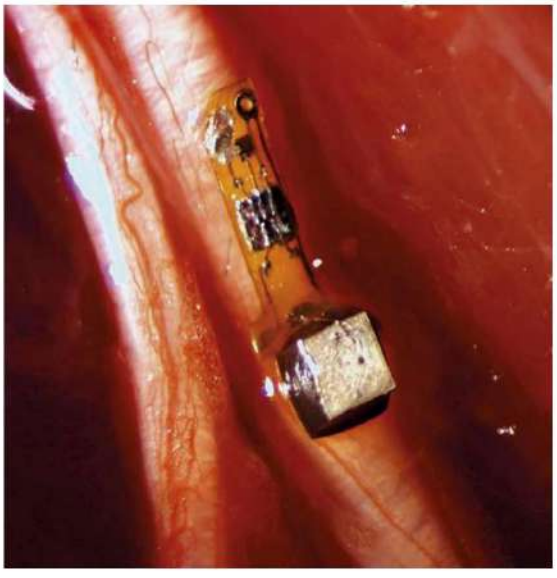
SHUTTERSTOCK, EKSO, NEURABLE

developing a blood pressure implant that would work by stimulating parts of the vagus nerve, which connects to the brain and is involved in regulating blood pressure.

At the same time, however, Stieglitz is bogged down in some of the engineering problems that researchers face in creating the early incarnations of these implants – problems that will have to be solved whether we want to cure epilepsy or conduct thought conversations with our friends. "The challenge is to design the system such that it can interact with the human body for an envisioned lifetime," says Stieglitz. That means finding a way to power it wirelessly inside the skull without having to remove it to charge the batteries, as well as making sure it doesn't damage the nerves that it interacts with or corrode in the watery environment of the body. According to Stieglitz, the latter problem may be tackled by making "soft implants" that mimic the floppiness of nerve tissue, but it would leave surgeons with a task akin to "implanting a jellyfish".

As well as practical issues, there's a minefield of ethical ones with implantable devices. DARPA, for instance, considers the "burden of surgery" too great and the risks too high for testing in able-bodied soldiers, while Valeriani believes it's better to invest in proven, non-surgical interfaces, which are far cheaper. Valeriani admits, however, that placing electrodes on the outside of the skull can't deliver anywhere near the level of detail that would be required for a whole-brain interface. External electrodes only allow neuroscientists to get a general idea of what regions of the brain are saying. Getting an accurate read-out from a single neuron requires going inside the brain and that means some major surgery. Or does it?





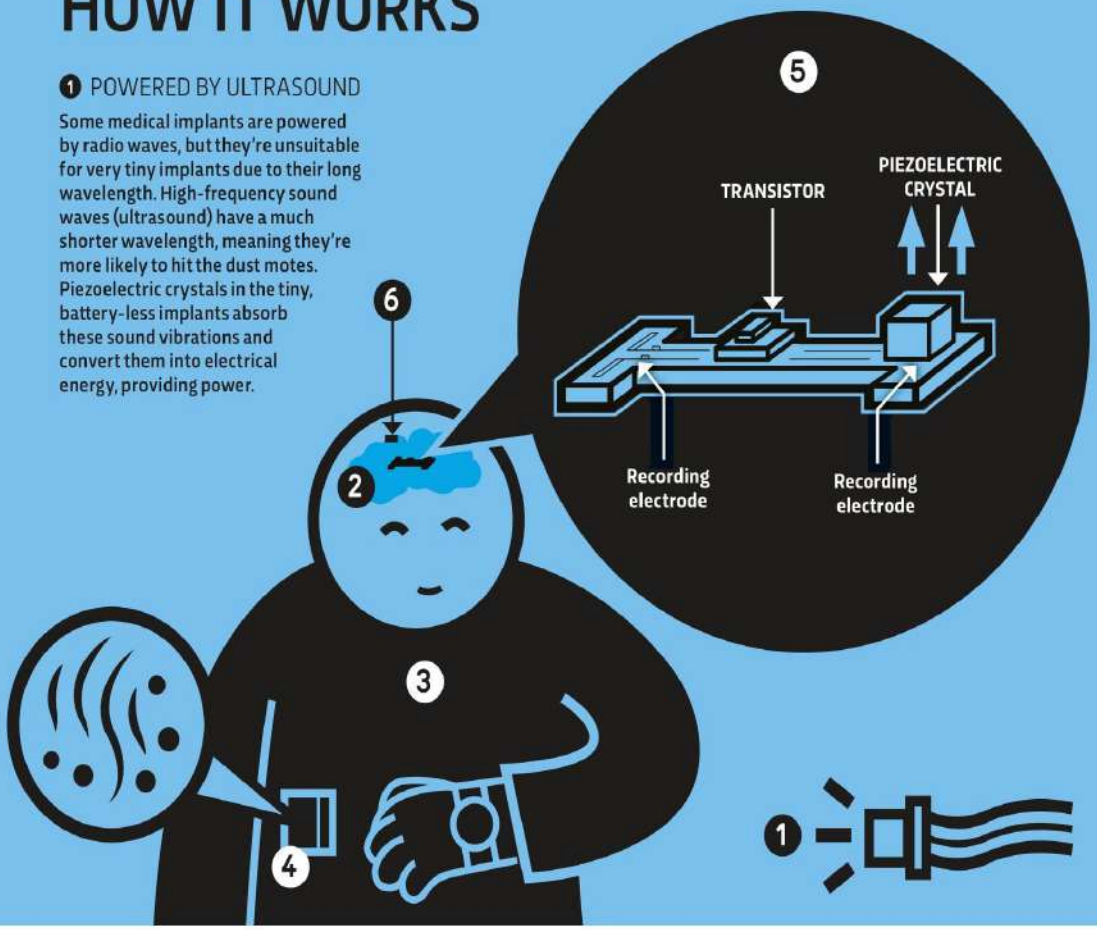
ABOVE: DARPA has developed this tiny device that can be implanted into blood vessels to record brain activity

LEFT: A team at the University of California, Berkeley, has implanted this 'neural dust mote' into the nerve of a rat

EAT MY (NEURAL) DUST

Five years ago, a team at the University of California, Berkeley, first described neural dust. Today, two of its inventors, Prof Jose Carmena and Prof Michel Maharbiz, are starting a neurotechnology company, Iota Biosciences, developing "vanishingly small" neural implants that they imagine being installed in a simple outpatient procedure – "in the same way that you get a piercing or a tattoo," explains Carmena.

NEURAL DUST: HOW IT WORKS



1 POWERED BY ULTRASOUND

Some medical implants are powered by radio waves, but they're unsuitable for very tiny implants due to their long wavelength. High-frequency sound waves (ultrasound) have a much shorter wavelength, meaning they're more likely to hit the dust motes. Piezoelectric crystals in the tiny, battery-less implants absorb these sound vibrations and convert them into electrical energy, providing power.

2 BRAIN DUST

Neural dust motes could be implanted in the skull by traditional surgical means. Eventually, the motes might be made so small that they're able to receive information from – or stimulate – individual neurons.

3 SPINAL FLUID

This could be a less-invasive route into the brain via injections if the neural dust is small enough.

4 PERIPHERAL PORTS

Motes could also be installed in parts of the nervous system that talk directly to the brain, making risky brain surgeries unnecessary.

5 WIRELESS COMMUNICATION

Reflections from the piezoelectric crystals carry information to the transceiver so that the implants don't need to generate their own signals, helping keep the devices low-power.

6 TRANSCEIVER

Provides the link between the dust motes and your computer, phone or fitness tracker. This could be placed just beneath the scalp or at a peripheral port.

UNIVERSITY OF MELBOURNE, NEUROLOOP. ILLUSTRATION: PHIL ELLIS

Using implants the size of grains of sand, they've already demonstrated that they can record and stimulate nerves in rats. They envision a bioelectronic future where we would have a bunch of neural dust motes implanted to keep tabs on our health via our fitness trackers, and treat everything from heart complaints to asthma just by tweaking the right nerves.

Except: how do you get the implants into the brain without opening the skull? One approach might be to wait until the technology scales down even further, so that the motes could be injected, perhaps into spinal fluid. DARPA, in fact, imagines something similar for its military devices. Its recent document covers nano-sized devices that would be delivered to the brain by "ingestion, injection or nasal administration".

Maharbiz, however, questions whether implants that small could do anything useful. In fact, the Iota pair believe it's possible to achieve "mind-boggling" things without tapping directly into the central nervous system at all. Instead, their dust motes could access the brain via its nerve branches in our limbs and organs, in a similar way to NeuroPace's blood pressure device. "There are other places in the nervous system where we think you can put these ports," says Maharbiz. "It won't give you the same bandwidth as having a thousand channels in your cortex, but you'll be surprised at how many things you can do by stimulating these peripheral nerves."

It sounds as if neural dust could be the perfect solution for anyone afraid of a little craniotomy. But could it also be used to build Elon Musk's whole-brain interface?

Interestingly, one of the Iota team's collaborators on the original neural dust paper was Dongjin Seo, who now works with Neuralink. While Musk remains silent on his new project, Carmena and Maharbiz know a few of the team and say there's "no hype at all" in the idea of them building a next-gen implantable brain interface.

But if anyone is going to up-end the world of brain-computer interfaces, you wouldn't bet against it being Elon Musk.

Hayley Bennett is a science writer based in Bristol.

LIFE ON MARS

While smart homes are the future on Earth, one day your great grandkids could be living somewhere else in the cosmos. So what will life be like for humans on a planet such as Mars?

WORDS: LEWIS DARTNELL AND KEVIN FONG

COLONISING MARS

How will we get to the Red Planet and what will life be like for the first colonists?

The race to Mars has begun. NASA's Orion programme is in full swing. Meanwhile Mars One – a private company staffed by former NASA and ESA employees – hopes to touch down on the Red Planet in 2032.

Once there, the first priority of new settlers will be putting in place the basic essentials for survival, and ensuring that backup systems are fully functioning. They'll have a lot on their minds. They'll need to ensure that all oxygen production and recycling equipment is working, and if they're topping up their oxygen from water gathered from the atmosphere (by breaking it down using electrolysis), they'll need to check that the extractor fans collecting atmospheric water are up and running.

In the first weeks, the colonists' food will not be home-grown. They'll be eating dried and preserved rations in boxes. However, they may spend the first two weeks setting up a simple greenhouse so that they can begin to grow food as soon as possible.

A crucial matter for survival is energy. Whether they're using nuclear or solar energy, they'll need to set up the apparatus, link it to the base and make sure that the power supply is stable and reliable. They may also set up chemical apparatus to make useful things like fuel. Carbon dioxide in the atmosphere, for instance, can be reacted over a catalyst with hydrogen (itself released from water gathered from permafrost or the atmosphere) to make methane fuel to power their robotic rover.

Most of these procedures will have been tested before they land, so in principle it should just be a matter of plugging in the equipment. But they will still need to check and cross-check all of these systems in a potentially lethal environment. The first few days will be a Lego-like frenzy of putting together the first Martian base.

Then, over the next few years, waves of new settlers will arrive and gradually build a larger colony on Mars...

ILLUSTRATION: MAGIC TORCH

HOME LIFE

Once the first colonists have settled in and more Martians arrive, what will day-to-day life be like?

HOME

The advent of 3D printing was a game-changer for space missions. At the end of 2014, the design for a socket wrench was emailed to astronauts on the International Space Station (ISS), who then used their 3D printer to create it.

Using a similar technique, researchers are now looking at designs for a home on Mars. Architects Foster + Partners plan to 3D print Martian regolith (the powdery rocky surface) onto a light, inflatable scaffold.

It remains to be seen how the regolith will be collected in sufficient quantities and delivered to the printer, and there would need to be tests in advance to ensure the system works in Mars's reduced gravitational field. But should it be successful, in an emergency a key piece of equipment could be designed, transmitted to Mars and printed within hours – much faster than the days it would take to dispatch it by rocket.

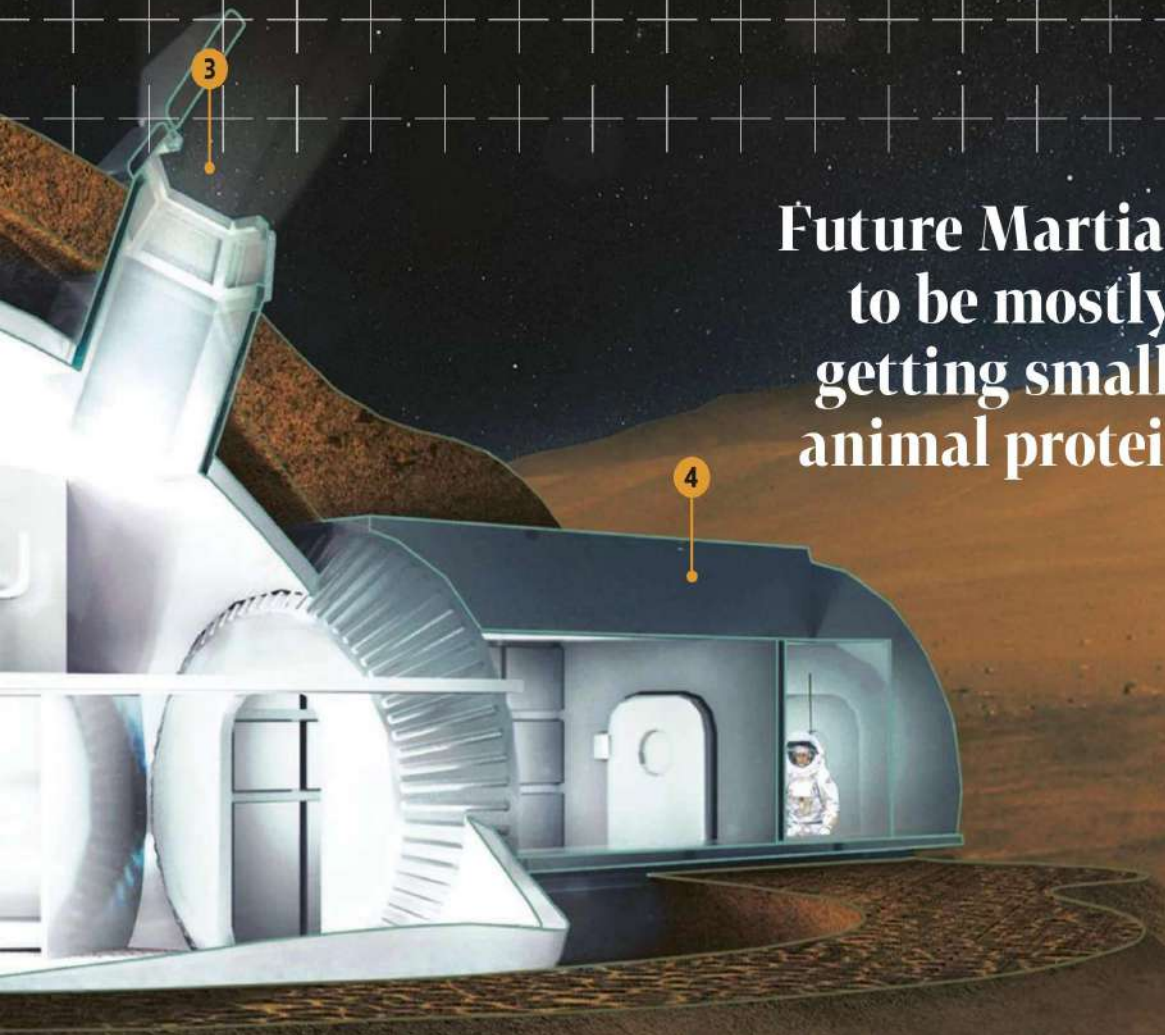
FOOD

Food deliveries from Earth would take far too long to get there. So Martians will need to be self-sufficient as space farmers.

In the film *The Martian*, Matt Damon's character cultivates potatoes in regolith mixed with his crewmates' excrement to provide nutrients. This isn't too far off the truth of what space agencies are considering for habitats on Mars (minus the poo). For example, in 2016, scientists at Wageningen University in the Netherlands made simulated Martian soil and tested which crops could be grown in it. They found that tomatoes, peas, radishes, rye and rocket grew well, but spinach struggled. They are now testing whether potatoes and beans could be cultivated on Mars. The environment is so hostile you would need to provide pressurised, inflatable greenhouses.

And what about meat? Keeping farm animals on an off-world base would be enormously

ESA/FOSTER & PARTNERS, NASA



Future Martians are likely to be mostly vegetarian, getting small amounts of animal protein from bugs

1. A 3D-printed shield protects from debris and radiation (see page 44).
2. The pressurised living area can house up to four people.
3. Skylights provide the Martian home with daylight.
4. The original capsule acts as an airlock and tech support module, with communication and equipment.

difficult – they would take up a huge amount of space and resources. So instead, future space explorers are likely to be mostly vegetarian, and get small amounts of animal protein from bugs. Insects can be reared in high-density and fed on plant waste. Taikonauts on China's Tiangong-2 space station have been raising silkworms, which could serve as a protein-rich source in the future. So perhaps future Martians will be eating bug burgers in home-grown wheat buns with lettuce and tomato.

WORK

Once a large colony is well established, all the usual jobs will need to be done – from rubbish collection to IT support. Many early colonists will be scientists, trying to find out as much as possible about the Red Planet – studying its geology to learn more about how it formed and what this might tell us about Earth's formation, looking for ancient signs of life to find out if it was ever inhabited – and if not, why a planet that was a little like the Earth in its early years remained dead, while our own planet became covered with thriving microbial life. Reconnaissance missions will scout for useful resources and locations for future bases. They could spend days away from the settlement, living and eating in their rover.

HOBBIES

We know from the accounts of those who've lived on space stations that looking after animals and plants gives people psychological reprieve from the extreme environment.

Outside the base there is a whole world to discover, whether that is painting the incredible landscape or going on treks to explore the planet just for the fun of it. Maybe as technical capacity improves we will attempt daring transpolar crossings of the great polar ice caps or expeditions across the Martian deserts.

HEALTH

As the Martian environment is hostile to the human body, we will have to develop ways to cope

KEEPING FIT

Martians will experience roughly one-third of the gravity that they would on Earth. We already know, from more than 50 years of human space flight, that weightlessness has effects on the human body. Bone and muscles waste rapidly and the heart, which is itself a muscle, deconditions. But other systems are also affected. Hand-eye coordination becomes impaired, the immune system gets suppressed and astronauts can become anaemic. Prolonged weightlessness can take athletes and turn them into couch potatoes.

Some authorities have proposed using short-arm centrifuges to provide a short burst of artificial gravity. Meanwhile, scientists have created a 'skinsuit' with a specific weave of elastic material that provides a graded tension between the shoulders and feet. This elastic loading on the body simulates 1g (Earth's gravity) and helps prevent stretching of the astronaut's spine and muscle and bone wasting. It was recently worn on the ISS by astronaut Andreas Mogensen.

What about developing drugs that could help make exercise in zero-g more effective or stop muscle loss altogether by blocking the degenerative process? Nathaniel Szewczyk, at the University of Nottingham, has been carrying out related research on microscopic worms. The nematode worm *Caenorhabditis elegans* has two muscle types that are similar to the heart muscle and skeletal muscles used for movement in humans. In experiments, Szewczyk and his colleagues found changes in the cellular production of around 100 proteins during spaceflight, many of them involved in muscle-building.

So scientists hope to develop a pill that will protect astronauts' hearts and muscles.

PROTECTING THE BODY

The thick atmosphere and global magnetic field that cocoons our planet protects the surface from cosmic rays. These are energetic radiation particles – spat out by flares on the Sun or accelerated to nearly the speed of light by supernova events – that are exceedingly hazardous to cells.

Martians will be exposed to this nasty space radiation. These energetic particles damage DNA causing mutations and could potentially trigger tumours and cancer, and they also turn the lenses of your eyes opaque.

Astronauts can be protected against cosmic rays by providing radiation shielding to absorb the particle bombardment, and this would be relatively simple on the Martian surface by burying the crew quarters underground.

Instead of blocking the radiation, another countermeasure would be to reduce its harmful effects within the body. Dietary supplements and drugs could be taken to mop up free radicals produced in your cells by radiation, or to help with DNA repair. Current antioxidant supplements aren't particularly effective, whereas radioprotector drugs like Ethyol do work but are pretty toxic.

ABOVE: Aerospace engineer Dava Newman developed this BioSuit for Mars missions. Its tight, elastic structure counteracts lower pressures

RIGHT: The crew of Mars500 – a psycho-social experiment, which tested how a team would cope in an isolated situation

NASA, ESA

Crew members have to be easygoing – you can't risk astronauts irritating each other

But, maybe one day we will genetically modify astronauts to enhance their radiation resistance. Scientists have been trying to find out what makes the microscopic animals called tardigrades so hardy. They found a new gene dubbed Dsup (for 'damage suppressor') which acted to prevent the tardigrade's DNA from breaking under radiation. And, astonishingly, this gene also reduced radiation-induced DNA damage by 40 per cent in human cells.

STAYING SANE

Long-duration space travel can take a heavy toll on your mental well-being. ISS astronauts often report problems with insomnia and loss of appetite, and it can be hard to find any privacy in the confines of the craft. Crews also have to be carefully selected to make sure that every member is easygoing – there is the threat of something going wrong, and you can't risk astronauts irritating each other too much.

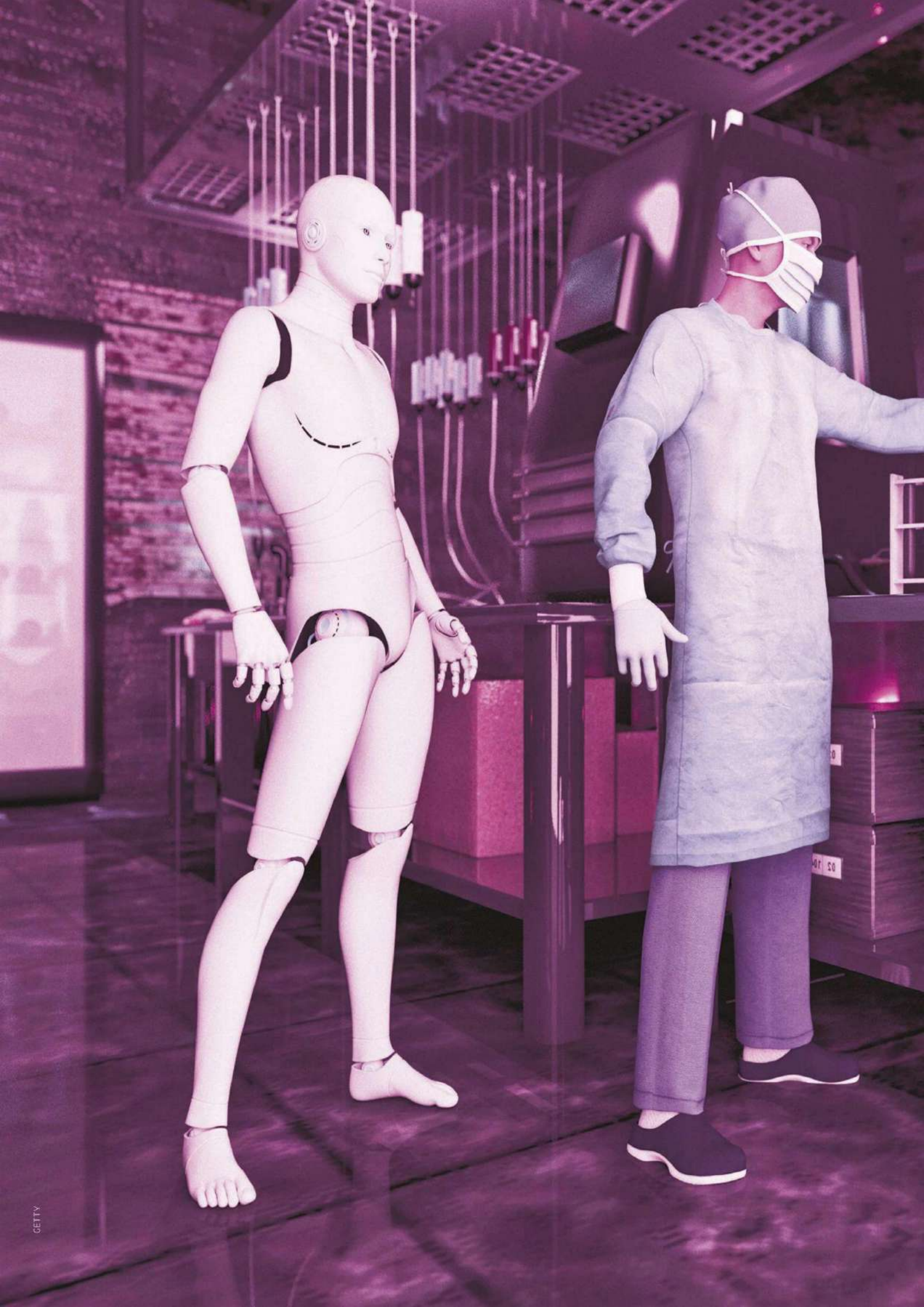
A good way to study psychological effects is in isolated situations on Earth. Dr Beth Healey has spent more than a year on the Concordia Station in the icy depths of Antarctica, as ESA's research doctor. During a polar winter you don't see sunshine for three months, and no evacuation is possible even in an emergency. In this sense, Concordia scientists are more isolated than ISS astronauts. In one of Healey's experiments, she got the crew to wear trackers, which monitored their location and, hence, when they isolated themselves or sought out social interaction. Healey also worked on a cognition test, which is now likely to be adopted into the astronauts' routines aboard the ISS. The test looks at lots of variables, such as risk-taking behaviour. Astronauts would take the test regularly, and any dip in performance would prompt mission control to step in. After all, keeping colonists sane could be the greatest challenge of all.

Prof Lewis Dartnell is an astrobiology researcher at the University of Westminster and author of *The Knowledge*.

Dr Fong has worked with NASA and is author of *Extremes: Life, Death And The Limits Of The Human Body*.

BBC RADIO 4

Tune in to *Mars Season* at bbc.in/2IqzREB



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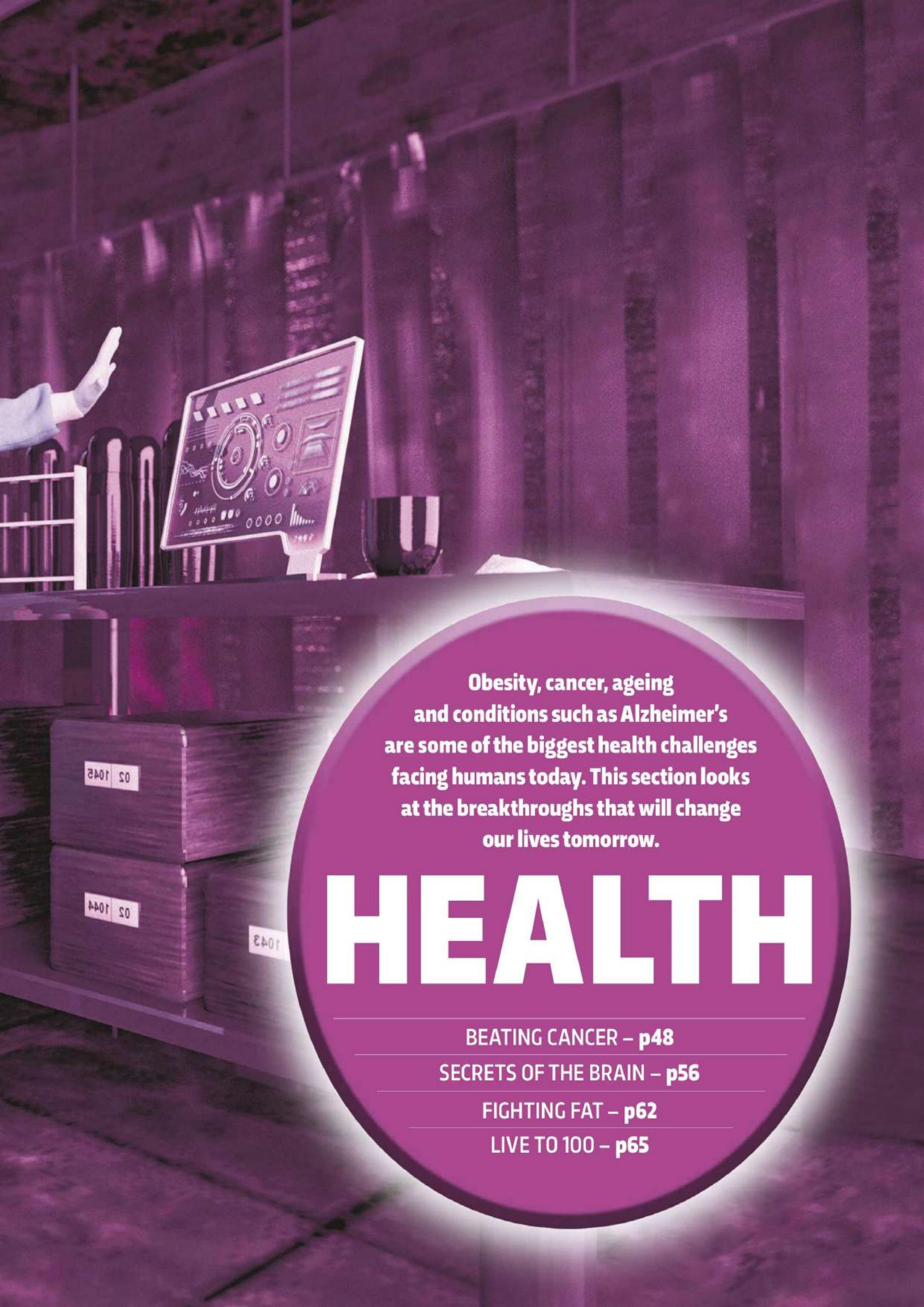


Obesity, cancer, ageing and conditions such as Alzheimer's are some of the biggest health challenges facing humans today. This section looks at the breakthroughs that will change our lives tomorrow.

HEALTH

BEATING CANCER – **p48**

SECRETS OF THE BRAIN – **p56**

FIGHTING FAT – **p62**

LIVE TO 100 – **p65**

ARE WE ON THE BRINK OF BEATING CANCER?

The numbers show survival rates of many forms of cancer have climbed dramatically over the last 50 years, but how close are we to finding a cure?

WORDS: SIMON CROMPTON

ALAMY

In 1971, US President Richard Nixon declared a war on cancer, proclaiming that the time had come "when the same kind of concentrated effort that split the atom and took man to the Moon should be turned toward conquering this dreaded disease."

Billons of research dollars later, are we winning the war? According to a report from Macmillan Cancer Support, people in 2016 are twice as likely to survive 10 years after a cancer diagnosis than at the start of the 1970s. Today, 69 per cent of women with breast cancer survive for seven years or more, and their chances of survival have doubled since the 1970s.

Seemingly every week brings news of another breakthrough. And, Cancer Research UK feels confident enough to state that by 2034, three in four people will survive cancer. So in less than 20 years, will cancer no longer be the dreaded disease it is today? Is it finally being beaten? Many cancer specialists will say as much – but what they mean by beaten varies.

"For the first time we've had patients with advanced disease actually being cured. That's extraordinary"

Some types of cancer are already curable. Nearly all men who get testicular cancer can be cured; UK mortality rates have decreased by 82 per cent since the early 1970s. New drugs have transformed the life expectancy for most people with chronic myeloid leukaemia (a blood cancer) from two or three years to normal. But other cancers are just as lethal as they were 50 years ago. Survival rates for pancreatic cancer, which kills 9,000 people in the UK annually, are just one per cent after 10 years.

The task of beating cancer seems all the more daunting in the knowledge that it's not just one disease but over 200, and every case has the genetic individuality of a snowflake. The last two decades have seen enormous advances in targeted drugs that home in on the particular genes and proteins found in specific cancers, but the chances of finding one that will hit all of them is still remote.

And what does 'winning the battle' mean, anyway? Doctors consider a patient's cancer to be cured when they've been disease-free for five years. But if the aim is for everyone who gets cancer to be 100 per cent disease-free for the rest of their lives, the war is just beginning.

Experts like Prof Clare Isacke, academic dean at the Institute of Cancer Research, believe that total cure should be the aim. But keeping everyone who gets cancer alive and holding the disease in check with treatments, is also a laudable and realistic goal.

Isacke is excited about recent developments in immunotherapy that boost the body's defence systems and help it attack the cancer. In 2016, a lady was cured of terminal breast cancer with treatment using her own white blood cells. And studies on skin cancer show that patients with widespread melanoma are still alive five years after being treated with new immunotherapy drugs such as nivolumab and ipilimumab.

"Everyone wants to rush out new versions of these kinds of drugs, because although they're not going to cure all cancers, for the first time we've had patients with advanced disease actually being cured. That's extraordinary," she says. "Improvements are going to come from multiple approaches – from prevention, advances in surgery and radiotherapy, all the way through to new drug treatments."

Over the next few pages, we'll look at some of the techniques we could harness to finally beat cancer for good.

ALAMY, GETTY

PREVENTING CANCER

BE GOOD TO YOURSELF

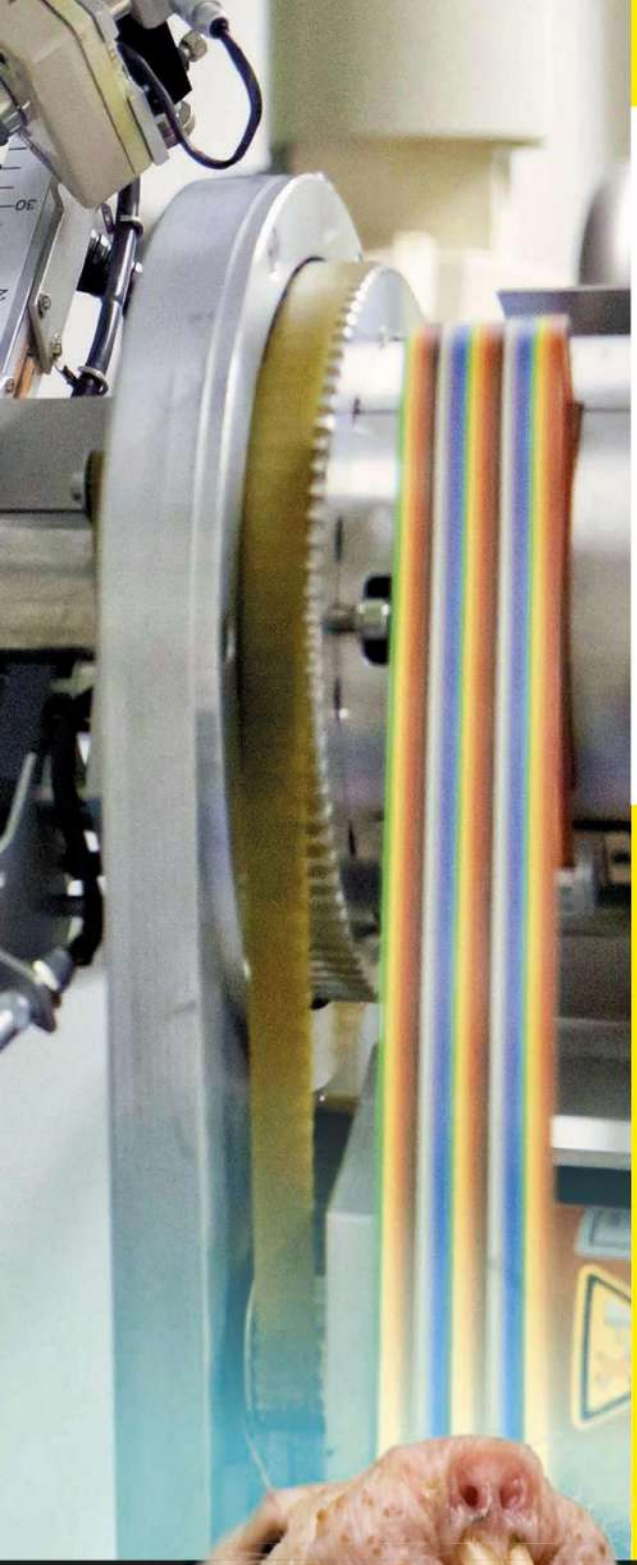
Preventing cancer may still offer the best prospect of conquering the disease. According to the International Agency for Research on Cancer, at least half of the world's cancers are preventable and it's possible that up to 90 per cent probably have an environmental or lifestyle trigger. One study suggested that if people simply acted on advice about smoking, diet, alcohol and other well-known risk factors, more than 40 per cent of UK cancers would be prevented. Researchers continue to find triggers. A World Health Organization review in 2016 established that drinking very hot tea or coffee does seem to be linked with throat cancer. This follows another global review that came to the conclusion that processed meat is carcinogenic.

BEFRIEND A MOLE RAT

Naked mole rats, which never die of cancer, are proving to be a valuable ally to scientists searching for ways of preventing the disease. The hairless rodents secrete a sugary goo made of hyaluronic acid, which not only makes their skin soft and wrinkly but also forms a protective cage around cells, preventing tumour cells from replicating. Scientists in London, Texas and Haifa in Israel are all now investigating whether genetic engineering might endow other mammals with a similar trait to the mole rat.

CATCHING CANCER EARLY

A blood test could detect cancer 10 years before symptoms appear



LEFT: A patient with eye cancer undergoes treatment that uses an ion beam

Naked mole rats might not be the prettiest of animals, but that wrinkly skin could hold the secret to beating cancer

Cancer is often curable if it's caught early: the real challenge comes when it spreads, and becomes complicated and resistant to drugs. This is why screening programmes (such as the ones that exist in the UK for breast, cervical and bowel cancer) to find the disease at its earliest stages play an important part in beating cancer.

But screening for cancer may soon be as simple as having a routine blood test. Doctors are already able to pick up specific markers in the blood of cancer patients to see if a particular cancer is returning, but they have to know what they're looking for. Scientists at Swansea University believe they've come up with a finger-prick blood test that might spot cancer in any person up to 10 years before symptoms appear. By studying patients with throat cancer, they discovered mutations that occur in red blood cells long before any other sign of the disease appears, and are now studying whether the same applies for pancreatic patients as well.

SCALPELS AND PROTON BEAMS

Surgery and radiotherapy cure more cancers than all the drugs combined. Surgery cures because the cancer can be cut out of the body straight after diagnosis, before it has had chance to spread.

Radiotherapy cures by exposing cancer cells to radiation, breaking their DNA and stopping them dividing. The problem with radiotherapy is the possibility of serious side effects, including impotence, heart problems, bowel incontinence and even a second cancer. But new techniques such as proton beam therapy and stereotactic ablative radiotherapy use such sophisticated targeting techniques that the benefits of the radiation far exceed the risks.

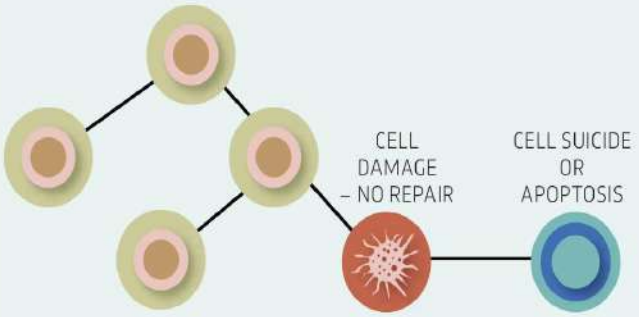
HOW DOES CANCER ARISE?

DNA inside every cell contains genes that provide coded messages about how the cell should behave. Normally, genes make sure that cells reproduce in an orderly way, only dividing into two when that's what's needed to keep the body healthy. Sometimes, though, genes get copied or damaged when a cell divides. This is called a mutation.

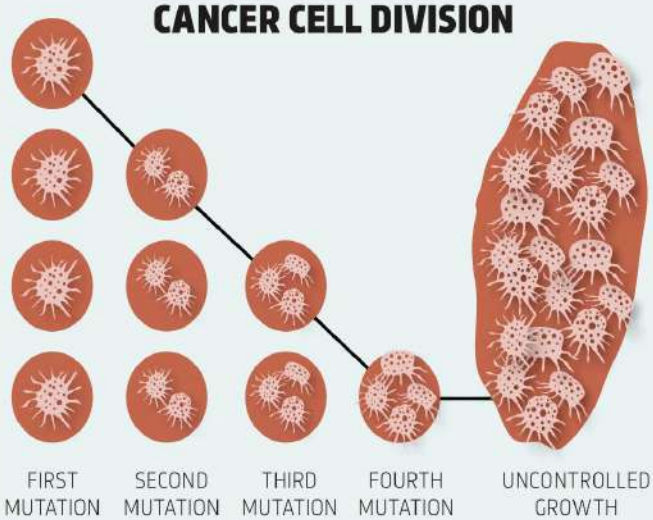
Normally, these damaged cells will self-destruct, but sometimes the damage prevents self-destruction. If this happens several times and mutations build up, it can mean that the cell no longer understands instructions regulating division. So cells divide out of control, forming lumps or tumours. Each time faulty cells reproduce, the more likely they are to produce new mutations, making them more different from healthy cells. Small groups of cancerous cells can break off the main tumour and be carried away to other parts of the body in the circulatory system. They form new tumours where they land, called metastases.

But why do cancer-causing gene mutations occur in the first place? Well, some people inherit faults in particular genes that make mutations more likely to happen. Exposure to environmental factors such as chemicals and tobacco smoke can also cause mutations. Most researchers believe that sheer bad luck also plays a part, since mutations are randomly caused by processes within cells.

NORMAL CELL DIVISION



CANCER CELL DIVISION



CURING CANCER WITH DRUGS

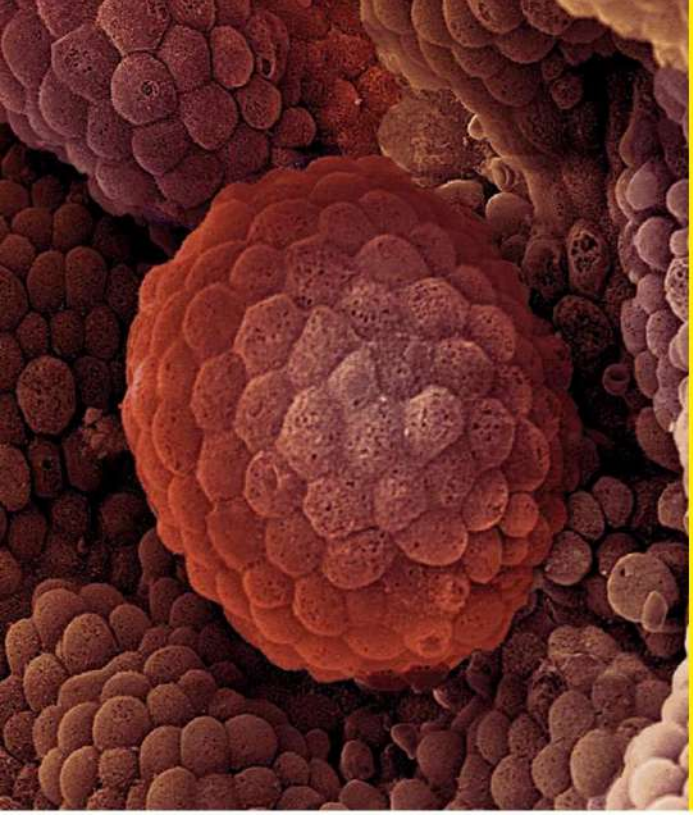
Could we press the 'pause' button on cancer?

The problem with most current cancer drugs is that they only work for so long. If cancer isn't caught early on, cells will continue to mutate rapidly, becoming more diverse and therefore trickier to target. But a remarkable discovery is providing a new understanding of this process.

Until recently, scientists believed that all cancers mutated in a linear fashion, with cells constantly changing but all of them genetically identical at any given point. However, new DNA sequencing techniques allowed researchers to read the genetic mutations in a tumour. This led to a groundbreaking study that busted the linear myth in 2012.

Researchers funded by Cancer Research UK and led by Prof Charles Swanton demonstrated that cancers evolve according to Darwinian principles, forming branch after branch off a main tree and giving rise to remarkable diversity within one tumour. Different samples taken from just one patient's kidney in the study revealed 118 different mutations. Yet a conventional biopsy might reveal just 25.

Since many modern drugs only target one mutation, the discovery makes the task of treating cancer sound even more daunting. Yet it provides a basis for new treatments that combine drugs. And understanding that cancers grow according to natural selection principles also provides researchers and drug developers with a focus: targeting the common mutations on the trunk of the evolutionary tree rather than the rarer ones on the branches that have sprung from the commoner mutations.



ABOVE: Prostate cancer, as seen in this image taken by a scanning electron microscope, tends to occur in older men and has an excellent cure rate

ABOVE RIGHT: Chemotherapy doesn't work on rapidly evolving cancers

BELOW: Activated T-cell attacking a tumour cell

"I think everyone now accepts that this diversity is the norm rather than the exception," says Swanton. "Everywhere I go now, people are talking about heterogeneity as the reason for drug failure, whereas in 2012 nobody was. As doctors, I think we need to think about how we can manage evolution in a clever way and, most importantly, learn from environmental ecology and say how we can structure clinical trials differently to take account of it."

KEEP IT ALIVE

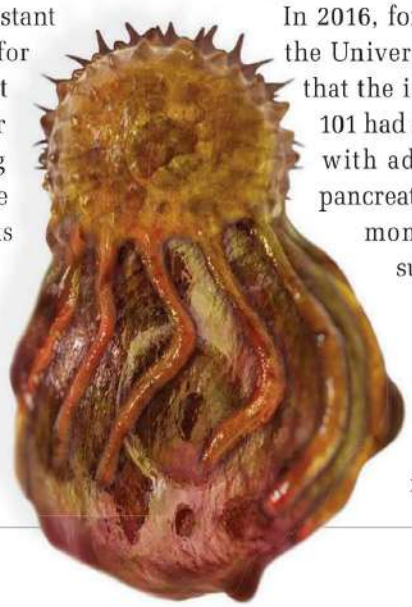
Because cancers evolve so quickly, they can rapidly become resistant to drug treatments, including chemotherapy. Drug-resistant cancer cells will survive and take over the tumour once the drug-sensitive cells have been killed off, so scientists are now exploring whether the best chemotherapy strategy is actually to keep drug-sensitive cells controlled but alive, so that they continue to out-compete the resistant cells. Researchers in Florida, for instance, have demonstrated that mice live longer if given lower doses of chemotherapy, controlling the cancer environment so that the law of survival of the fittest works for patients, not against them.

BOOST THE IMMUNE SYSTEM

Immunotherapy – stimulating the body's defence mechanisms to recognise and fight cancer – was hailed by the scientific journal *Science* as 2013's most groundbreaking advancement. Since then, excitement at this game-changer has grown. The technique involves working with the immune system or introducing man-made antibodies to attack cancers. Scientific trials have already shown immunotherapy to be extremely effective at treating particular forms of cancer, with tumours in some cases completely disappearing.

In 2016, a lady was cured of terminal breast cancer after scientists screened her white blood cells, extracted those capable of attacking the cancer, multiplied them in the lab and injected 90 billion of them back into her bloodstream.

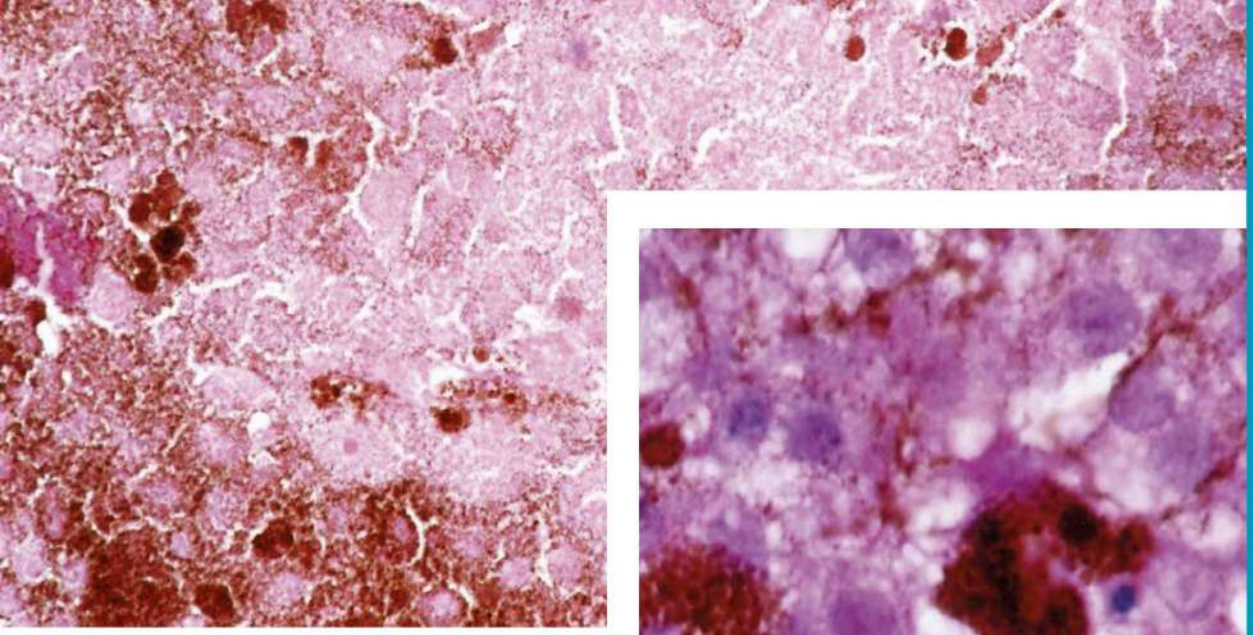
Meanwhile, patients in England and Wales whose melanomas had spread around their bodies have become the first in Europe to benefit from a powerful combination of immunotherapy drugs called nivolumab and ipilimumab. But the applications may be much wider than that.



In 2016, for example, scientists from the University of London announced that the immunotherapy drug IMM-101 had extended the lives of people with advanced and metastasised pancreatic cancer from four to seven months, with some subjects surviving for up to three years.

Scientists from Sweden announced earlier that same year that they'd found new ways to prevent cancers concealing themselves from immunotherapy

GETTY X2, SCIENCE PHOTO LIBRARY



The above image is a biopsy taken from a malignant melanoma; the image on the right was taken from the same patient following treatment with tumour-infiltrating lymphocytes

BBC RADIO 4

Watch a clip about new targeted treatments for leukemia
bbc.in/2t02jrn

approaches, by activating immune cells (macrophages) within the tumour to make it more recognisable.

New knowledge of the ways that cancers evolve, gained from analysing the DNA of hundreds of patients, is uncovering ways to precisely guide immune cells to all cancer cell types in a tumour. Researchers from the Cancer Institute at University College London have discovered that as a tumour develops, its genetic faults are 'flagged' in proteins on its cells. And even though these faults are diverse, all cells show the 'flag' of its very earliest mutations. This paves the way for therapies that specifically activate immune cells that target all cancer cells, because they carry a common genetic flag.

"What better system to target the diversity of a tumour and its dynamic nature than the very system that has evolved over four billion years to do just that – the immune system?" says Swanton. "Trying to predict the future is impossible, but I'm hopeful that in my lifetime we're going to see some changes in the management of this disease. But it's a massive challenge and a battle of wits with evolution."

CANCER VACCINES

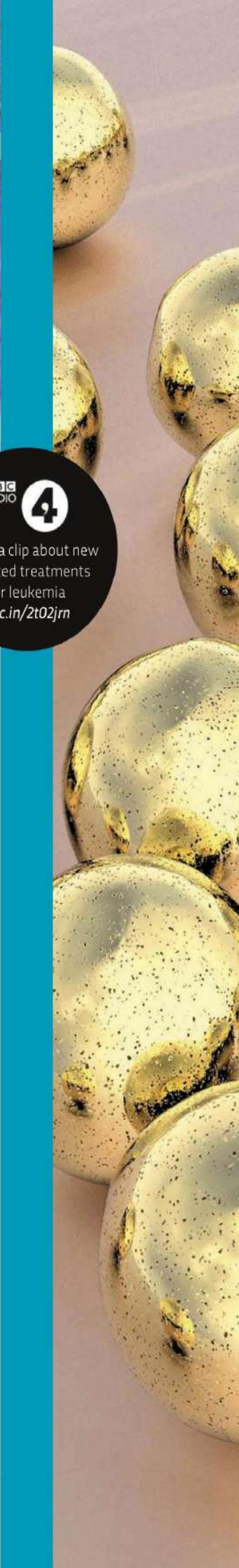
A jab that prevents cancer was once seen as a Holy Grail. But, with advances in immunotherapy, the prospect of a cancer vaccine no longer seems the outlandish proposition it was 10 or 20 years ago.

The human body's immune system often ignores cancer cells, because they're hard to distinguish from normal cells. But a new injection currently being tested in Germany smuggles cancer's genetic material (RNA) into the body via nanoparticle capsules. The nanoparticles appear similar to viruses, so the body's defence system is activated and taught to recognise and destroy cancer cells. The scientists believe that this research may pave the way for a universal cancer vaccine.

Another type of vaccine is being trialled that could prevent recurrence of cancer in those patients who've already been treated for the disease. Researchers have found that a particularly potent type of immune cell called a tumour-infiltrating lymphocyte (TIL) can be harvested from a patient's tumour after it has been surgically removed. Analysis can reveal which of the TILs are active against the patient's own tumour and these can then be injected back into the patient to minimise the risk of the cancer coming back.

The Centre Hospitalier Universitaire Vaudois, in Lausanne, Switzerland, is currently building a new cell-processing facility to produce these personalised vaccines. George Coukos, the director of oncology at the hospital, believes that such treatments could transform the prospects of curing cancers of all types in little more than a decade.

"Immunology brings the prospect of drugs that are universal," explains Coukos. "In a decade we could be in a position where, for the first time, we could see a drastic reduction in the relapse rate, and therefore a drastic increase in the cure rate."



SCIENCE PHOTO LIBRARY 2

Nanoparticles can be used to destroy tumours

NEW TARGETING APPROACHES

Rather than pumping your entire body full of drugs, modern treatments can home in on cancer cells alone

NANOPARTICLES AND LASERS

Danish researchers have developed new treatments in which nanoparticles are injected into the cancerous tumour. Lasers outside the body are then used to heat up the nanoparticles, burning the cancer cells from within. Unlike chemotherapy and radiotherapy, this treatment avoids damage to surrounding tissue.

Nanotechnology is already being employed to deliver highly targeted medication to cancer patients. Drugs can be chemically bonded to nanoparticles that accumulate in tumours and release their payload in the affected site.

TROJAN-HORSE DRUG DELIVERY

Another new targeting system, which has been tested on prostate cancer cells, uses engineered stem cells to carry potent chemotherapy drugs direct to cancer sites. Researchers from Brigham and Women's Hospital in Boston say that these 'Trojan Horse' approaches provide new ways of treating a cancer that has spread through a patient's body, without poisoning the whole body with chemotherapy drugs.

SALMONELLA HELPS OUT

Researchers at Swansea University are enlisting the help of Salmonella bacteria to carry anti-cancer weapons to the heart of tumours. Salmonella bacteria have a natural tendency to find their way to tumours, then invade and multiply. The research team has engineered the bacteria to be harmless to patients, so they can carry cancer-killing molecules to tumours.

Simon Crompton is a freelance journalist and editor who specialises in science and health.

UNLOCKING THE SECRETS OF THE BRAIN

FROM AUTISM AND SCHIZOPHRENIA TO ALZHEIMER'S, LAB-GROWN MINI-BRAINS COULD BE THE KEY TO SOLVING THE BIGGEST MYSTERIES ABOUT HUMAN DEVELOPMENT AND DISEASE

WORDS: **KAT ARNEY**

Stacks of petri dishes in a laboratory incubator, each one holding a blob of human brain might sound like the stuff of science fiction. But this is no flight of the imagination: these mini-brains, known as organoids, are being cultivated in labs all over the world, and researchers believe they could unlock some of the secrets of how our brains grow and what happens when they go wrong.

"I don't think that any of us set out to try and grow a brain in a dish," says Madeline Lancaster, a neurobiologist at the MRC Laboratory of Molecular Biology in Cambridge. "If you'd asked me even just a few months before I started working on it, I'd have said it was completely nuts – but in my case, it was an accident!"

Lancaster's accidental experiments with organoids started when she was a postdoctoral researcher working in Vienna, investigating how the brain develops in the womb. She started by growing brain stem cells in flat layers in a dish, but soon realised they lacked many of the key characteristics of nerve cells in a real brain. In search of a better method she tried a new technique for growing neural 'rosettes' – flat, flower-like circles of cells that were more realistic, albeit still two-dimensional.

"When I put the cells in the culture dish, there was something wrong with the reagents that I was using," she says. "Rather than forming these nice flat rosettes, mine were forming these weird, floating balls."

ILLUSTRATION: MAGIC TORCH

Speaking to other researchers, she discovered that some of them had also seen these strange blobs, but had thrown them away because they looked wrong. But Lancaster kept growing hers and what she found inside was fascinating. Each was made from bulging layers of cells connected by cavities, just like the fluid-filled ventricles that connect the hemispheres of the cerebral cortex in a real brain. Even the layers of cells mimicked the arrangement in normal brain tissue, with stem cells lining the ventricles and layers of more specialised cells and neurons built up towards the outside.

One of Madeline Lancaster's cerebral organoids, seen here in cross-section

BUILDING A BRAIN

Despite their 'mini-brain' nickname, these organoids are a long way from being full-size human organs. They're around half a centimetre in diameter – roughly the size of the eraser on the end of a pencil – and they lack key structures such as blood vessels, which limits how big they can grow. Organoids are also hardy, provided they're grown in a scrupulously clean environment, and can stay alive for more than a year.

Despite their 'mini-brain' nickname, these organoids are a long way from being full-size human organs

Lancaster's mini-brains are enabling her to prise open the 'black box' of human brain development. "People have done MRI scanning on children and babies to look at how the brain's wiring changes. But when it comes to those early events – how neurons are made, how many, which types and where – we can't see them, no matter how good our MRI machines are. But I think what's happening in these dishes reflects what's happening in an actual embryo. We know this because the end product looks a lot like a real brain, so we have a tractable system to start asking some fundamental questions about brain development."

Mini-brains don't just allow researchers to study normal developmental processes. Sergiu Pasca, assistant professor of psychiatry and behavioural sciences at Stanford University in California, is using them to understand what goes wrong in autism, schizophrenia, epilepsy and other neuropsychiatric disorders.

"Most of the psychiatric drugs we have today have been discovered by chance – we know very little about the origins of these disorders. Unlike cancer biologists, who can take out a tumour, put it in a dish and find ways to treat it, we can't do that with the brains of our patients with mental disorders!"

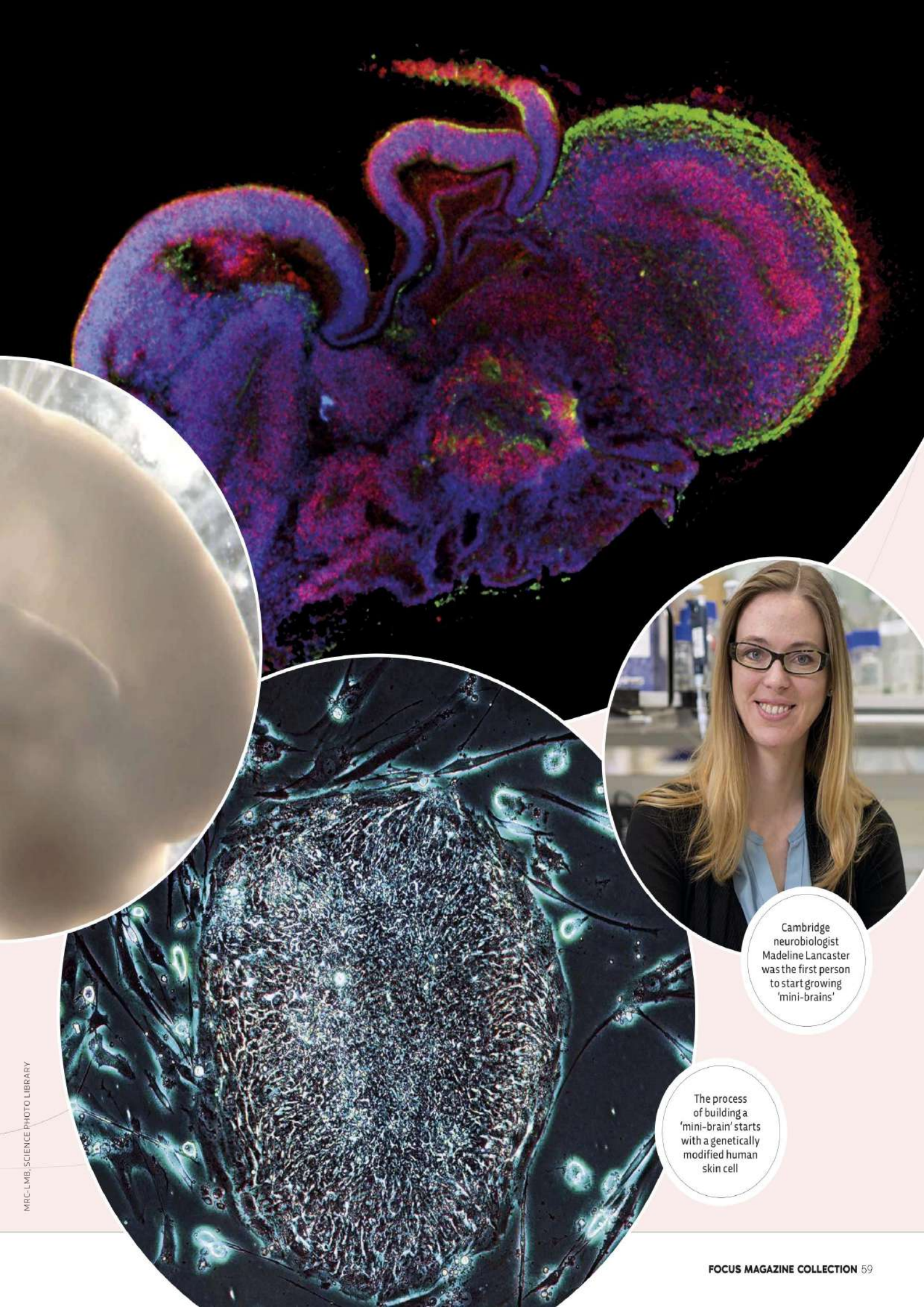
Pasca and his team have managed to keep mini-brains growing for more than two years – 800 days is their current record – and have shown that their organoids can generate most of the same cell types and structures that occur in real human brains.

They're using the technique to investigate the roots of severe autism and epilepsy syndromes, by generating organoids with induced pluripotent stem (IPS) cells derived from skin samples of affected children and then carefully comparing them with cultures grown from healthy cells.

"We can use electrodes to measure how the cells are talking to each other and microscopy to see how the cells move and make connections," he explains. "Many of the genes associated with these disorders are involved in the connections between nerve cells, so we can see how the gene changes in these patients are impairing the communication within the brain in a non-invasive way."

He's now taking the process even further by sticking together organoids that mimic different regions of the brain and studying their interactions – a technique he describes as 'brain Lego'. The team is using these hybrid mini brains to observe the brain as it gradually wires itself up. The 'brain Lego' approach allows them to focus on what happens to the so-called inhibitory neurons that normally ➔

A bright-field microscopic image of a cerebral organoid. In real life, this 'mini-brain' is 1cm across



Cambridge neurobiologist Madeline Lancaster was the first person to start growing 'mini-brains'

The process of building a 'mini-brain' starts with a genetically modified human skin cell

MRC-LMB, SCIENCE PHOTO LIBRARY

help to calm down brain activity but are faulty in people with epilepsy and autism.

"Inhibitory neurons aren't born in the cortex on the surface of the brain: they're born in a deep region of the forebrain and have to migrate over many months after birth," Pasca says. "It's fascinating to watch in our cultures – they kind of pull themselves up and jump along."

But when Pasca and his colleagues looked at organoids grown using cells from patients with a form of autism associated with epilepsy, they saw a very different picture. The inhibitory cells were moving in a peculiar way, jumping more often but less efficiently and eventually getting left behind.

The researchers were then able to identify a drug that could rescue these lagging cells, correcting the wiring defect and, in the process, provide clues for a potential treatment for children suffering from the same condition.

Mini-brains mimic the very earliest stages of life, while dementia is a problem that takes decades to develop

INTO OLD AGE

Meanwhile at University College London, neurologist Selina Wray is using brain organoids to look at neurodegenerative conditions that start at the other end of life, including Alzheimer's disease and fronto-temporal dementia.

"Normally we have to work with post-mortem brain tissue from patients, but you're only ever looking at the end stages," she says. "It's like coming to the scene of a crime after the criminal is gone, and you're trying to piece together a sequence of events by looking at the damage that's been left. I want to build models in the lab that will let us look at the beginning of the disease – because if we understand the first things to go wrong, that's when treatment should be more effective."

In a similar way to Pasca and Lancaster, she's taking skin samples from patients with dementia, turning them into IPS cells and then growing organoids. Wray can spot differences between organoids grown from dementia sufferers' samples and organoids from unaffected people after just a few months, finding increased levels of certain molecules associated with Alzheimer's disease.

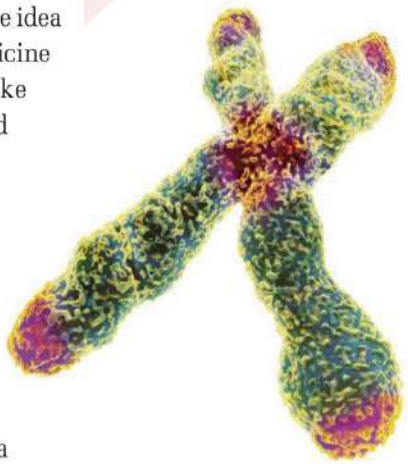
But there's a problem with this approach: mini-brains mimic the earliest stages of life, while dementia is a problem that takes decades to develop. To solve this, researchers are finding ways to speed up the ageing process. One idea is to add in genetic changes that mimic progeria – a rare disorder that causes premature ageing. Another is to meddle with the structures protecting the ends of DNA, known as telomeres, which act as a kind of countdown clock as we age.

As well as studying the underlying processes that drive dementia, Wray thinks that mini-brains have a lot of potential for helping to identify the right treatment for individual patients.

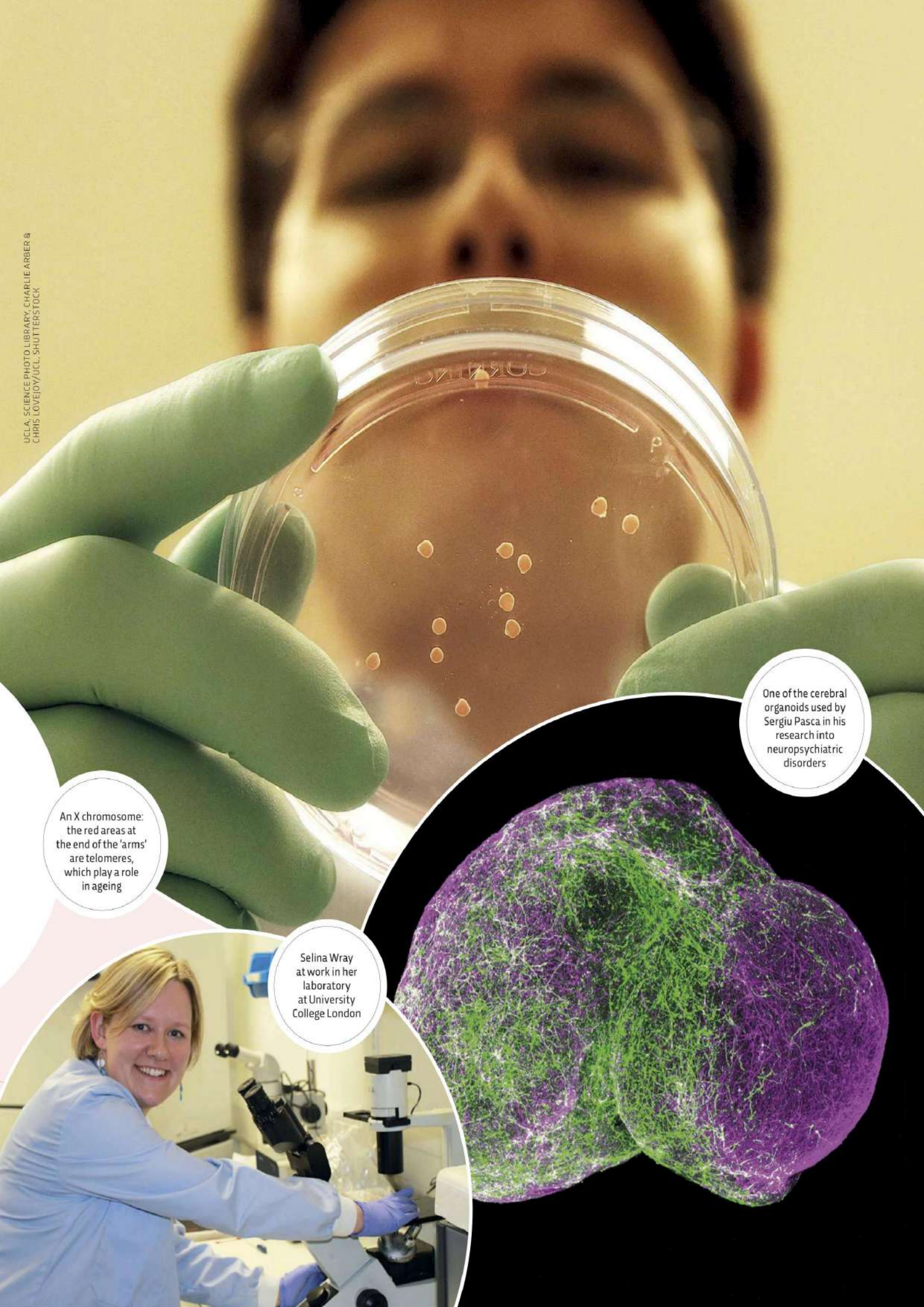
"I feel excited by the idea of personalised medicine – that you could take somebody's cells and grow organoids in the lab, screen a panel of drugs against them and say, 'Okay, we think this person will respond to drugs ABC, but this other person will respond better to drugs XYZ,'" she says. "That's happening in cancer biology, this idea of being able to stratify patients on a molecular basis. And while I think we're a long way off, I love the idea of growing someone's neurons so we can work out what therapies we should be giving them."

Sergiu Pasca is similarly enthusiastic about the potential of mini-brains to change lives. "Our organoids are grown from cells taken from real patients – kids with severe neurodevelopmental disorders," he says. "And to think that a few months later you can derive brain tissue from those patients in a dish and start asking questions about how the disease may arise – that's what makes this exciting."

Sergiu Pasca holding 'mini-brains' used to study the development of conditions such as autism



Kat Arney is an author and broadcaster who presents *The Naked Scientists* on BBC Radio 5 Live. Her latest book is *How To Code A Human*.



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An X chromosome: the red areas at the end of the 'arms' are telomeres, which play a role in ageing

One of the cerebral organoids used by Sergiu Pasca in his research into neuropsychiatric disorders

Selina Wray at work in her laboratory at University College London

FIGHTING FAT WITH SCIENCE

Since time immemorial, the control of food intake and body weight was thought to be simply an issue of self-control. Gluttony is, after all, one of the seven deadly sins. But obesity has become a major public health problem. In the UK, 64 per cent of adults are overweight or obese. So how can science fix the problem?

WORDS: **GILES YEO**

GETTY

Let's start with what we know. One of the pathways involved in obesity is the fat-sensing leptin-melanocortin pathway. The hormone leptin is produced from fat and tells your brain how much fat is stored in your body, while the melanocortin pathway in your brain senses leptin levels and influences food intake. We know this pathway is critical to the control of food intake, because genetic disruption of either the leptin or the melanocortin pathway causes obesity in humans.

We now know of over 100 genes that are linked to obesity. These genes, which include many found in the melanocortin pathway, mostly function within the brain to influence food intake. The evidence tells us that having more risk variants of these genes makes your brain less sensitive to hormones from the fat and gut, with the effect that some of us feel more hungry all of the time.

Not eating when you're not hungry is easy. But have you ever tried to stop eating when you're still hungry? It's very difficult because it's not what we're designed to do. We've evolved to eat when food's available, not to stop. Thin people don't have iron willpower, they just feel less hungry, so get full up more easily. Equally, obese people aren't weak willed, they're fighting their biology. In essence, an obese brain thinks that you have less fat than you actually do, and that you ate less than you actually did at the last meal, leading you to eat more at the next one. You may only eat five per cent more, but a little more every day adds up to a big difference over a lifetime. But a recent discovery might mean that, in future, you won't be able blame your genes if your jeans don't fit.

ENERGY-BURNING FAT

The majority of the fat cells in your body are 'white' and they store energy. But the smaller group of brown fat cells burn energy, as they have more energy-generating mitochondria – hence, the brown colour.

Scientists have known for a while that people with a low body mass index have more brown fat. But, earlier this year, a team at the Salk Institute for Biological Studies in the US found the protein in brown fat that's key to its fat-burning ability. The scientists also discovered that brown fat cells express the ERRγ gene, which codes for the protein that enters the cell nucleus and controls the expression of other genes.

While more research is needed, this breakthrough looks promising in the battle with obesity. "This could lead to new ways to control the amount of brown fat in the body, which has links to obesity, diabetes and fatty liver disease," says senior author Ronald Evans, Howard Hughes Medical Institute investigator and holder of Salk's March of Dimes Chair in Molecular and Developmental Biology.

BBC TWO

Watch a clip from *Horizon: Why are we getting so fat?* bbc.in/2IWEIEO

Giles Yeo is the principal research associate at the MRC Metabolic Diseases Unit, University of Cambridge.

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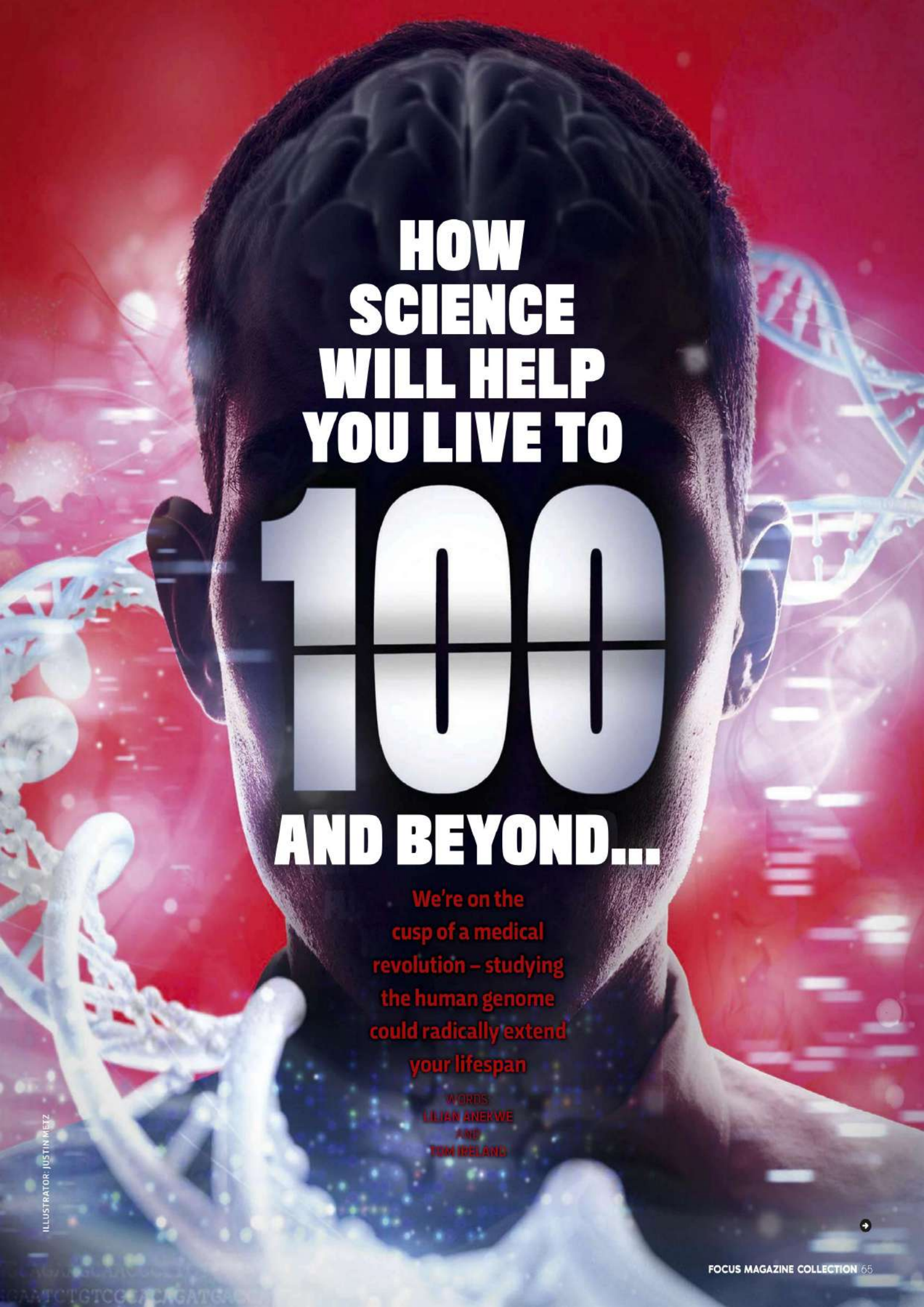


HOW SCIENCE WILL HELP YOU LIVE TO 100 AND BEYOND...

We're on the cusp of a medical revolution – studying the human genome could radically extend your lifespan

WORDS
LILIAN ANEKWE
AND
TOM IRELAND

ILLUSTRATOR: JUSTIN METZ

What if you could live past 100? Would you want to? These are questions we might all need to consider. In recent years some of the world's highest-profile pioneers have turned their attentions to finding the genes that could make us live forever. Their aim: to hunt down the illnesses that affect us in old age.

The leader in this race to help us live longer is Craig Venter: the geneticist, entrepreneur and philanthropist behind the Human Genome Project. In 2014, he announced that he was investing $70 million (£53m) of venture capital to set up Human Longevity Inc (HLI).

But Venter isn't alone. In September 2013, Google CEO Larry Page revealed that he'd appointed Art Levinson, chairman of Apple and biotechnology company Genentech, as CEO of Google Calico (California Life Company). Calico has the ambitious remit of improving human health and well-being, and solving the challenge of ageing and associated diseases.

A GIANT UNDERTAKING

Calico and HLI are fledgling companies with bold promises, especially when you consider that only a handful of trial patients have received treatment based on genomic research. So it begs the questions: how will they stop ageing? And what will treatment look like?

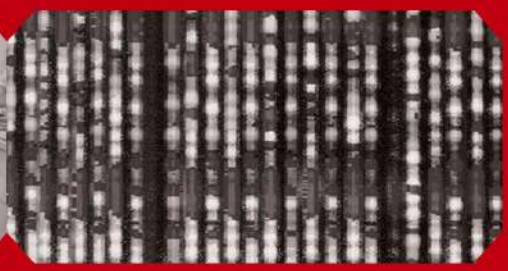
Venter's company, HLI, has created the world's largest database of sequenced genomes and phenotypic (physical traits) data in the hope that this gives insights that could transform healthcare. At the same time HLI is cataloguing the bacteria that live in and on the human body (the microbiome), and sequencing the metabolome – the genetic information about the biochemicals in the body.

It's a huge undertaking but Venter is confident this big genetic data approach

The genomic pioneers, from left to right: Art Levinson, Larry Page and Craig Venter

WHAT WILL THE NEW AGE OF MEDICINE LOOK LIKE?

The amazing therapies on the horizon that will help you live longer



STEM CELL THERAPIES

As we age our stem cells are depleted and degraded. But a new stem cell treatment suggests we may be able to reverse the process of ageing. 'Switching on' four genes associated with stem cells appeared to reverse some signs of ageing in both human skin cells and live mice.

PERSONALISED MEDICINE

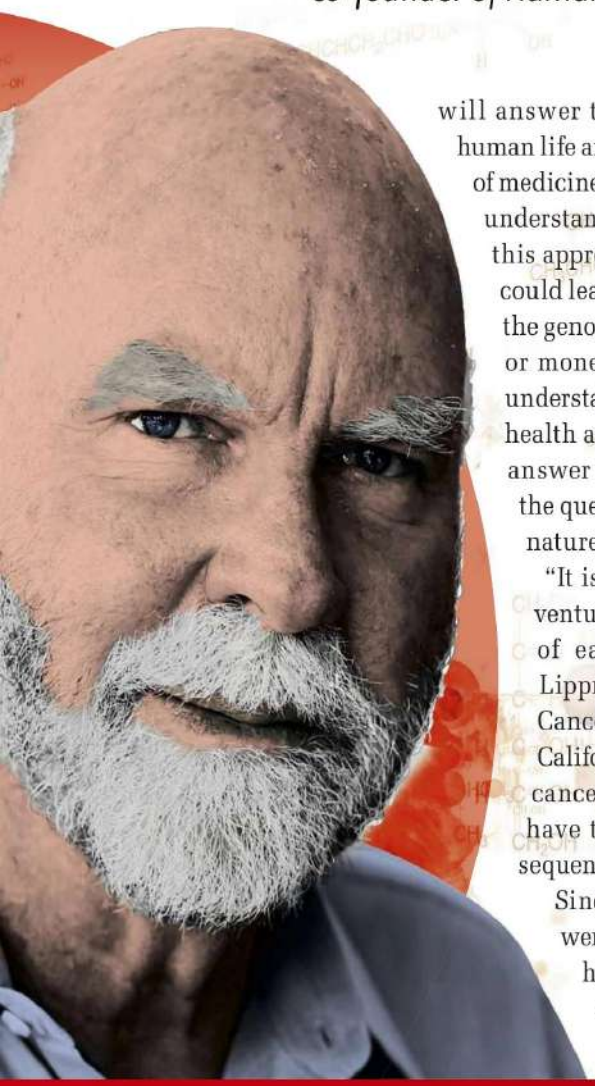
Surprisingly, a lot of medications have little or no therapeutic effect on a lot of people. Genomic data could tell us who will respond to a drug and why certain drugs work better for some people than others. It could allow doctors to choose the most effective drugs for patients with the least side effects.

PREVENTATIVE MEDICINE

If you could find out how long you have left, would you want to know? You could discover what your genome (human DNA sequence, pictured) says about your risk of cancer and have an optimum longevity package and customised preventative advice to help you make it to a century.

"We think we can answer for the first time in history: what's nature and what's nurture?"

Craig Venter, *biologist and entrepreneur, co-founder of Human Longevity Inc*



will answer the biggest questions about human life and death to usher in a new age of medicine. "We're likely to gain a better understanding of human lifespan with this approach," he says. "But if all we could learn about was the sequence of the genome I wouldn't waste my time or money. The potential is to truly understand our genetic propensity for health and disease. We think we can answer for the first time in history the question everybody asks: what's nature and what's nurture?"

"It isn't a coincidence that these ventures launched within months of each other," says Dr Scott Lippman, director of the Moores Cancer Center at the University of California, San Diego – where every cancer patient who consents will have their genomes and tumours sequenced by HLI.

Since the first human genomes were sequenced in 2011, the field has progressed at a rapid pace and now cancer researchers are at the cusp of "the next frontier in science", explains Lippman. "Right now we're in a period that's going to be transformational for cancer, in a similar way that the '90s were for the internet. We understand the genome and the technology means sequencing on this scale can be done more quickly and cheaply than before. What used to take us 15 to 20 years we can now do in a year or two. The cancer field is moving very quickly and this is just the tip of the iceberg."

According to the World Health Organization, cancer caused 8.8 million deaths in 2015 and was the second highest global killer in 2017 – nearly one in six deaths was due to the disease. And, for the most part, cancer is a disease associated with old age.

HLI plans to use the genome data it generates from sequencing to identify and analyse the genes involved in cancer and find potential new treatments.

GETTING PERSONAL

The sequencing of genes will be just one battlefront in the war against ageing. Dr Razelle Kurzrock, director of personalised cancer therapy at Moores Cancer Center, sees other ways that HLI's genome catalogue could change medicine. "At the moment we're lumping people with different cancers together. That's been helpful to a limited extent, but it's been hard to make great leaps using these techniques," she says. "That's because 100 lung cancer patients may all have different abnormalities that drive the growth of their cancer. Only a small fraction will respond to a treatment.

"In the past, we haven't been able to differentiate which patients will respond to treatment or which will have side effects. Genomics should allow us to personalise therapy according to people's genetic profile – this is the basis of personalised therapy. It's my belief that personalised therapy will spread to influence all of medicine. The potential is enormous."

The hope is that what HLI learns about cancer can be applied to diabetes and obesity, heart and liver diseases, and dementia. But finding treatments for these illnesses may not be enough to increase human longevity. After all, it's estimated that even if we found a ➔

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FAECAL TRANSPLANTS
The bacteria in our guts (pictured) changes with age. There's a theory that suggests we can use a microbiome analysis to identify someone with 'young' gut bacteria and transplant poo, which contains their gut bacteria, to rejuvenate the microbiome of an older person.

BIOINFORMATICS
Researchers at IBM and the New York Genome Center (pictured) are designing software that cancer doctors can use to upload an analysis of your genes and mutations. The software would study your genetic code and provide a list of relevant drug options that should work best for you.

cure for cancer this would only increase the average human lifespan by a few years – before people die of a different disease.

This is why, according to Venter, the goal of solving one illness – even one which is as big a threat to human health as cancer – is not HLI's ultimate aim. "While we're all going to die of something, your age is your number one risk factor for every disease," he says. "In the last few decades the average human lifespan has increased. Fewer people are dying from cancer and heart diseases, but more are living longer with illnesses like dementia that impact quality of life. I wouldn't necessarily call that a healthy lifespan. So the goal isn't just to extend lifespan – it's to extend the healthy human lifespan."

"What used to take us 15 to 20 years we can now do in a year or two. The cancer field is moving very quickly"

Dr Scott Lippman, *director of Moores Cancer Center at the University of California, San Diego*

FAULTY GENES

The mechanisms that control human ageing are complex. What we know about the genetics of ageing comes from studies of families, twins and centenarians – people who live beyond 100 years. Longevity tends to cluster within families, and parents and siblings of centenarians have a greater likelihood of living to an advanced age than other people.

GETTY X4, ALAMY X2

5 THINGS YOU COULD TRY TO LIVE TO 100

BE SOCIAL

Having friends and family for support during stressful times in life is vital to reaching 100. One study by researchers at Brigham Young University found that people with a solid group of friends are 50 per cent more likely to survive at any given time than those without one.

Masa Narita of Osaka, Japan turned 100 in 2014; keeping her social life going has helped make her a centenarian

STAY POSITIVE

Studies of the children of centenarians found that they're more extroverted and less neurotic than other kids. Similarly, a study in the journal *JAMA Psychiatry* found that people who feel they have a sense of purpose in life tend to live longer. So stay busy and lighten up.

The family of Canada's Tomiko Kadonaga (101 in 2013), say that the secret to her long life has been her sense of positivity

GET MOVING

Being sedentary has been linked with diabetes, obesity, heart disease and cancer, and a study in 2011 estimated that our lives are about 22 minutes shorter for every hour we spend sitting watching TV after the age of 25. So why not get up and read this article standing up?

Now 107, Fauja Singh became the first ever 100-year-old to finish a marathon – the Toronto Waterfront Marathon in 2011

BALANCE YOUR DIET

Studies of rats fed a calorie-restricted diet have found this can double their lifespan. But this hasn't been proven in humans. In regions where centenarians are common (Okinawa, Japan, and Sardinia, Italy), their diets include very little, if any, processed food.

Dorothy Newell celebrated her 100th birthday in 2014. Eat a balanced diet and you could see as many candles on your cake

...AND SLEEP

A study of over a million American adults carried out by researchers at the Scripps Clinic Sleep Center in the US, found that people who slept between 6.5 and 7.5 hours a night lived the longest. People that slept more than 7.5 or less than 6.5 hours a night didn't live as long.

Seven hours' kip a night is the optimum amount to live longer – maybe think about resetting that alarm clock

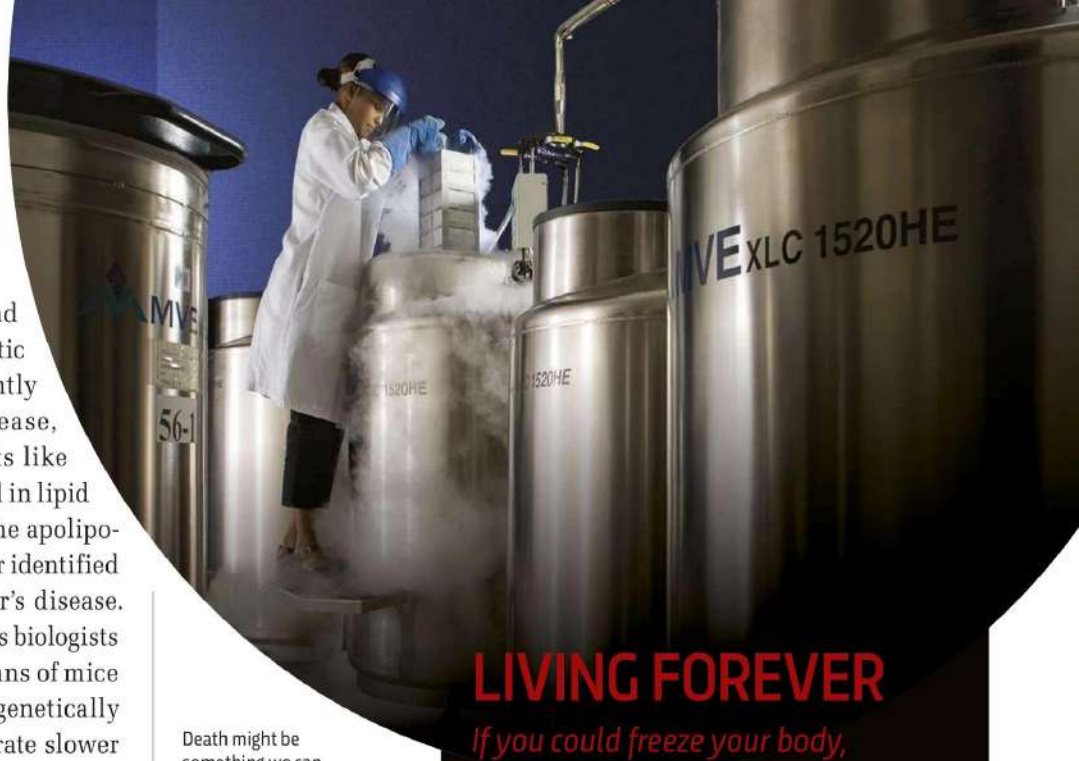
From studying these families and searching the genome for small genetic variations that occur more frequently in people with a particular disease, researchers have identified targets like apolipoprotein E, a protein involved in lipid metabolism. A genetic variant in the apolipoprotein E gene (ApoE E4) is the major identified risk factor for late-onset Alzheimer's disease. By manipulating these kinds of genes biologists have been able to extend the lifespans of mice by as much as 50 per cent. These genetically modified mice live longer, degenerate slower and develop diseases later.

We still don't know if genes identified by the HLI sequencing could be manipulated in humans, but Dr João Pedro de Magalhães, from the integrative genomics of ageing group at the University of Liverpool, says the HLI data will provide a good place to start finding out. "In mice we can retard all aspects of ageing – molecular, cell, longevity and disease – by genetic manipulation. We don't know that it's possible in humans but there's no reason to think it's not. Sequencing is the place to start. Genomics has huge potential for ageing. It's an ideal process for the large-scale analysis like Human Longevity Inc is proposing."

EARLY DAYS

It's too early to know what secrets HLI has tapped into by hacking human genomes for the last few years. But Dr Kurzrock is convinced that the most revealing insights will come from comparing the genome sequences of her patients at the Moores Cancer Centre with healthy people. "In my work I've seen people in their 30s and 40s who smoke and already have advanced lung cancer, while other people smoke heavily and still make it to 100 in robust health. Is this luck? I very much doubt it."

Venter firmly believes his approach will drive this area of research further and is prepared to gamble on the success of his venture. "In the last 15 years there haven't been that many breakthroughs that have changed medicine. [But with this] I believe we can make giant leaps. If we don't have substantial breakthroughs in preventative medicines I'll be very disappointed. But the odds of that happening are low." F



Death might be something we can overcome if we ever solve the problem of defrosting complex human tissue without causing irreparable damage

Lilian Anekwe is deputy editor of *Chemist+Druggist* magazine.

Tom Ireland is a science writer and editor of *The Biologist*.

BBC RADIO 4

Listen to an episode of *FutureProofing* on ageing
bbc.in/2HI8KES

LIVING FOREVER

If you could freeze your body, would you want to?

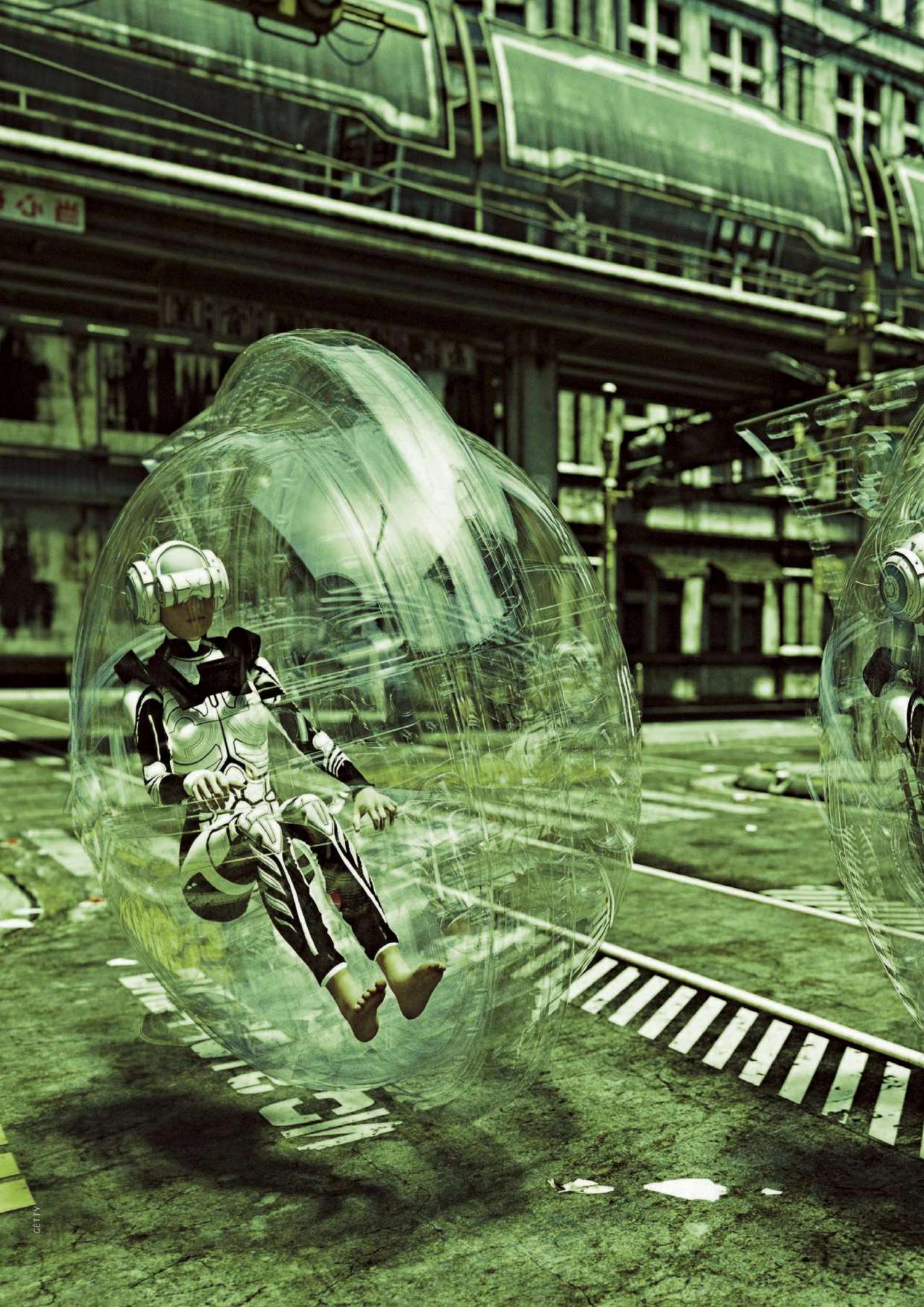
The idea of freezing people in the hope of reawakening them isn't new. Fifty years ago, James Bedford became the first person to be cryogenically frozen and his body remains in cold storage to this day. Various companies have offered similar services in the years since, often using hopelessly crude freezing techniques or failing to store the bodies properly.

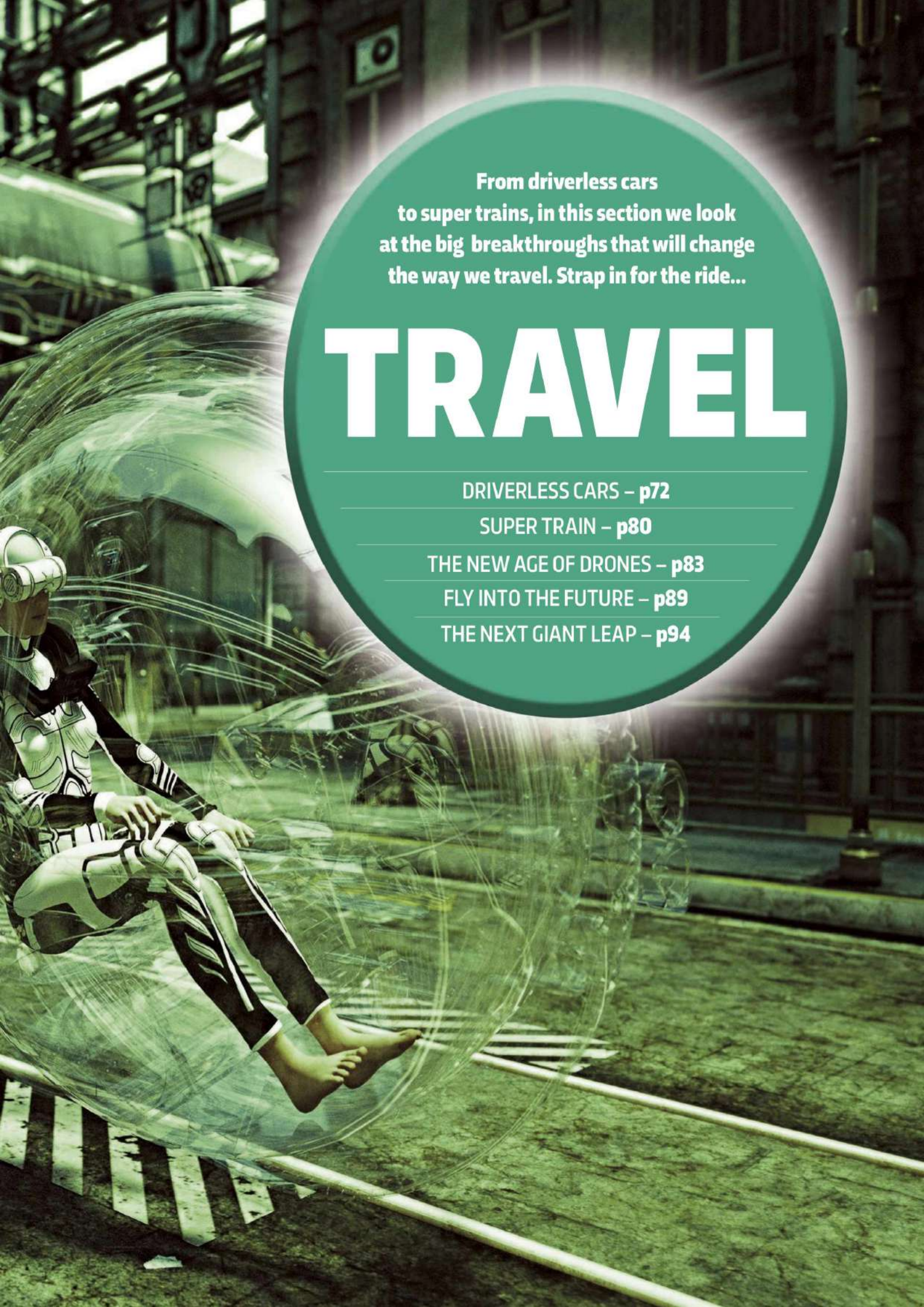
Today, the cryogenic freezing of human stem cells, sperm, eggs, embryos and other small tissue samples is a routine part of scientific research and reproductive medicine. But de-frosting a whole body, made of many different tissue types, would be far more complex.

Vitrification, a process that turns samples into a glass-like state rather than ice, was developed in the early 2000s as a way of overcoming the problems of ice forming in and around cells. Ice can cause dramatic differences in concentration inside and outside the cell, sucking water out and destroying it. A team led by vitrification pioneer Gregory Fahy used a cocktail of antifreezes and chemicals to cryopreserve a rabbit kidney. The organ appeared to function normally after it was thawed and put back into its donor.

But cryonics is unique in that it's utterly reliant on technology that doesn't exist yet. Even if so-called 'patients' are frozen perfectly after death, they're simply guessing that scientists will one day be able to reanimate them and cure their illnesses – and will want to. Perhaps a more feasible way to extend life may be uploading our minds onto a computer, which would free us from the restraints of a physical form entirely.

Banking on these future technologies is a big gamble, especially when the costs of cryonic preservation start at around $30,000. Yet for people whose lives are cut short by illness, a miraculous breakthrough may be the only hope. An example is the 14-year-old British girl who made headlines in 2016 by expressing her wish to be frozen, before she died of cancer. A judge ruled that her wishes must be respected and her body was frozen. She wrote: "I'm 14 years old and I don't want to die, but I am going to. Being cryopreserved gives me a chance to be cured and woken up in hundreds of years' time."





From driverless cars to super trains, in this section we look at the big breakthroughs that will change the way we travel. Strap in for the ride...

TRAVEL

DRIVERLESS CARS – **p72**

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THE NEW AGE OF DRONES – **p83**

FLY INTO THE FUTURE – **p89**

THE NEXT GIANT LEAP – **p94**

Are we ready for driverless cars?

Self-driving cars can take much of the danger out of driving, but they also present us with new problems to solve. So what needs to be figured out before the autonomous vehicle technology gets the green light?

WORDS: **ROB BANINO**


Self-Driving
GETTY

Remove humans from the driving equation and cars will be safer. That's the thinking behind the push for autonomous vehicles.

"Autonomous vehicles reduce the risk of collisions, and that's recognised by insurers," says Ian Crowder from the Automobile Association (AA). "If the tech proves to be much more reliable than humans, who can be subject to tiredness, stress or distraction... there's every possibility that situations that would typically lead to collisions will be removed."

Safer cars and safer roads are attractive prospects, in both human and financial terms. According to the Department of Transport and the Department of Business, Innovation and Skills, the intelligent mobility market is estimated to be worth £900bn annually globally by 2025. This is why car manufacturers are pushing to develop the vehicles, and why the UK government is investing heavily to help them. In 2016, £39m of a £100m fund was awarded to projects working on enhanced comms systems between vehicles and roadside infrastructure, and trials of autonomous vehicles in Greenwich, Bristol and Milton Keynes.

Given that people's lives are at stake if an autonomous vehicle fails, perhaps the roads aren't the best place to test the technology until we can be sure it's more reliable

But what's controlling these cars if there's nobody at the wheel? The short answer is a lot of extremely sophisticated technology. Audi, the first manufacturer to receive permits to test autonomous vehicles on public roads (in Nevada in 2013 and Florida in 2014), uses differential GPS (said to be accurate to within a few centimetres), 12 radar sensors (to scan the road in front of the car), four video cameras (to spot road markings, pedestrians, objects and other vehicles), a laser scanner (that emits nearly 100,000 infrared light pulses per second, covering a zone of 145° on four levels around the car to profile its surroundings) and a powerful computer to process everything the sensors detect. And all of those systems need to work together so that the car always knows where it is, where it's going and what's around it.

SEEN IN A BAD LIGHT

Some of these systems have been shown to work, and have found their way into cars with adaptive cruise control or parking assist. But relying on them to safely conduct a journey on open roads alone is a big step. Still, it's a step that many companies including Tesla, Google, Fiat Chrysler, Renault-Nissan and Uber (with the help of Volvo) are in the process of taking. Although their efforts have, on the whole, been safer than normal cars (in terms of the number of accidents per miles driven), they have encountered problems. For example, Renault-Nissan's CEO Carlos Ghosn admitted to CNBC that the system in its vehicles is confused by cyclists "because sometimes they behave like pedestrians, and sometimes they behave like cars".

Meanwhile, the cameras on Tesla's vehicles have been said to struggle with the glare from sunshine, particularly at dawn or dusk. And sunlight's not the only natural phenomenon that can throw a spanner into the works: rain interferes with what a driverless car 'sees' through its cameras, and reduces the effectiveness of any laser scanners, as the drops can bend and reflect the light pulses.

Problems like these have led to some high-profile incidents. In December 2016, Uber had to withdraw the 16 test vehicles it was trialling in San Francisco after California's Department of Motor Vehicles revoked the cars' licences. The local authority said that the ride-hailing company didn't have a permit to operate autonomous vehicles on the city's roads, but

its decision came after footage emerged of the vehicles running red lights and veering into cycle lanes. Then in March last year, Uber temporarily suspended its self-driving programme after one of its cars flipped onto its side in a crash in Tempe, Arizona.

Perhaps the most notable failure happened in May 2016, when a Tesla Model S running in Autopilot crashed into a truck in Florida, killing driver Joshua Brown. Tesla told investigators that the Autopilot was not at fault, but there had been a "technical failure" of the automatic braking system.

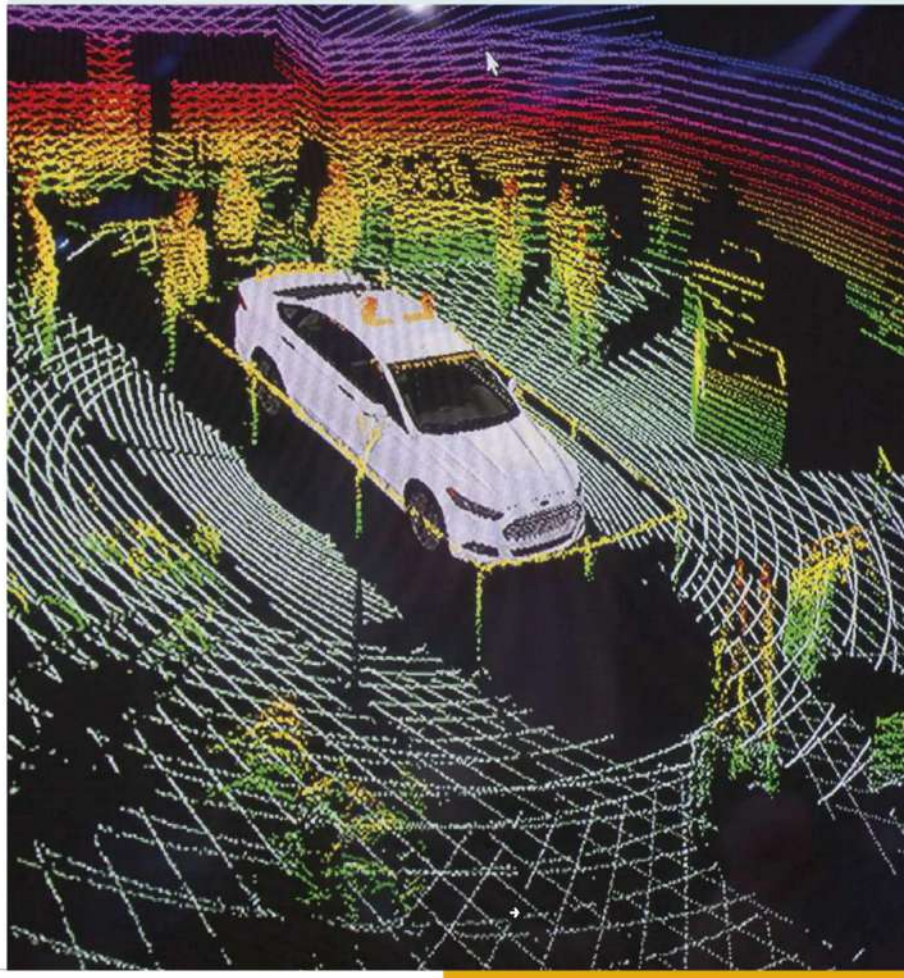
TESTING THE COMPETITION

Failures are to be expected during the testing and developmental phases. "It's only through using the technology and trying it in real life that it's going to be improved, because even the best developers are not going to recognise every possible scenario that an autonomous vehicle might encounter," Crowder points out. But given that people's lives are at stake if an autonomous vehicle fails, perhaps the roads aren't the best place to test the technology until we can be sure it's more reliable. Especially when we could put autonomous vehicles through their paces in another way: motor racing.

"In many ways we're ahead of the

ABOVE: Fortunately, there were no injuries when an Uber self-driving car crashed in Arizona

BELOW: Autonomous vehicles use a wide variety of sensors to 'understand' their surroundings



ALAMY, REUTERS

HOW COULD DRIVERLESS CARS CHANGE MOTORING?

It's early days for autonomous vehicle technology but it has the potential to have some profound effects. Especially if it completely rules the driver out of the equation...

PARKING

Some cars already have 'parking assistance' that allows the vehicle to manoeuvre itself into tight spots. But they require the driver to be there 'just in case'. If a driverless vehicle could be trusted to park itself, it could drop you off at your destination and find a space on its own.

LEARNING TO DRIVE

It's likely that anyone operating a vehicle, autonomous or not, will still require some sort of training in order to do so. But the arrival of autonomous vehicles is expected to result in changes to the Highway Code and possibly the skills taught while a new driver is learning.

TAXIS

If a car can take you anywhere without you having to drive, why do we need taxi drivers? Uber has stated that its plan is to eventually operate an autonomous fleet. So while it may be goodbye to awkward conversations with drivers, there may also be considerable job losses.

SLEEPING

If autonomous vehicles reach a point where the controls can be entirely handed over to the car, there'd be no need to stay awake during the journey. You could simply get in, buckle up and nod off. That would certainly make the M6 a lot more pleasant...

TOURISM

You're visiting a city and you want to see the sights. Would you rather get on a tour bus, or hop in a car and let it ferry you from one destination to the next? While it might be fun to jump on an open-top bus, there's always the threat of rain spoiling the trip.

ROAD HAULAGE

Van and lorry drivers can only be at the wheel for a specific number of hours each day. Autonomous vehicles could make long trips without rest stops. Faster journeys and greater fuel efficiency equals lower costs... and potentially another career in jeopardy.

industry," says Justin Cooke, the chief marketing officer of Roborace, the championship for autonomous electric vehicles that's expected to debut this year. "Roborace was developed to evolve technology that will be used on the road, and accelerate the speed at which both electric and autonomous technology is being tested for road cars."

But despite the speed and competition, racing is arguably a less extreme test environment as there are no pedestrians, roadworks, junctions and crossings to worry about, and all of the traffic's moving in the same direction – albeit very fast. Hence, unlike the autonomous vehicles being trialled on the road, the Roborace cars won't have someone onboard to take control if something goes wrong. So what happens if a car goes awry during the course of a race?

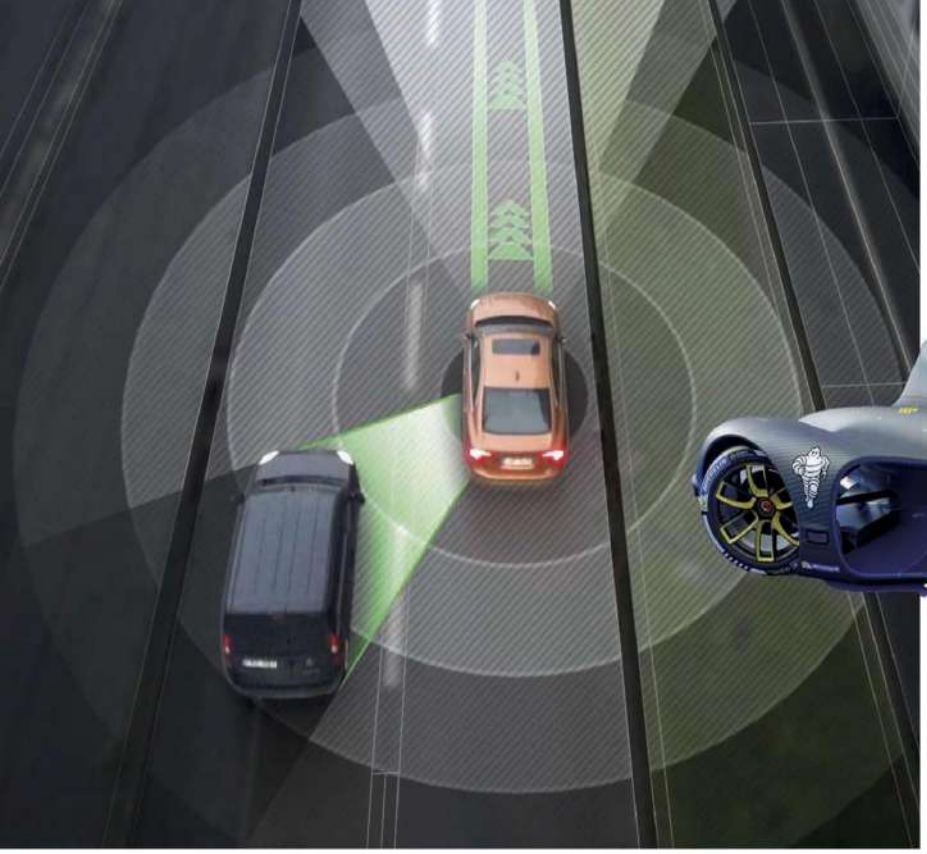
"All the cars will be equipped with a 'safe stop' that the engineers control back in the pit," explains Cooke. "If the car goes off course for any reason, it can be brought to an immediate stop using this button. In fact, it's even safer than a human-driven race car, as the robocar can literally stop instantly, because there's no delay from a human reacting to a problem and then performing an emergency stop."

The cars' first competitive public outing in February last year brought mixed results. Two driverless cars took to the city-centre circuit ahead of the Formula E race in Buenos Aires but only one finished. The other overshot a bend and crashed into the barriers – although, encouragingly, the car that completed the race not only achieved a top speed of 186km/h (116mph) but also successfully avoided a dog that strayed on to the track.

THE BLAME GAME

Road-going autonomous vehicles don't have the luxury of a pit crew, however. Which is why the vehicles being tested on our roads need to have a qualified driver in the driver's seat ready to take control in case of emergency. It's a policy that's likely to be retained if – or more probably when – autonomous vehicles are given the go-ahead, meaning you won't be able to stumble out of a pub drunk and expect your car to drive you home.

But this approach creates more conundrums:



If – or when – autonomous vehicles are given the go-ahead, you won't be able to stumble out of a pub drunk and expect your car to drive you home

if the 'driver' isn't actually driving, doesn't that make them a passenger? And if the driver fails to react correctly and has an accident, is it their fault or the car's? The more cynically minded might see this as a 'get out of jail free' card for manufacturers of autonomous vehicles. Uber blamed the instances of its cars running red lights in San Francisco on human error, and there are reports that Joshua Brown was watching a film when his Tesla crashed.

"It does raise issues for insurers, because you have the transfer of liability if there's a collision involving a driverless vehicle," says Crowder.

The Association of British Insurers is pushing car manufacturers to ensure that autonomous vehicles can collect core data in the event of an accident, and that the information is made available to prevent drivers being unfairly blamed. The data would cover a period from 30 seconds before to 15 seconds after an incident, and provide a GPS record of the time and location of the incident; confirmation of whether the vehicle was in autonomous or manual mode; if, while in autonomous mode, the vehicle was parking or driving; when the vehicle went into autonomous mode, and when the driver last interacted with the system.

But what if someone hacks the vehicle? This has already been proven possible with conventional vehicles: cyber security experts Charlie Miller and Chris Valasek have managed to take over various vehicles' electronic control units remotely. Hacking is therefore an enormous concern for everybody, not just in terms of losing control of the vehicle but also regarding what that vehicle could then be used for.

The people who abuse the technology – the thieves and hackers – are often the ones who can design the best security systems. Uber certainly thinks so: the company hired Miller and Valasek shortly after they demonstrated what they could do to a car being driven miles away, using only a laptop.

Although autonomous vehicles have the potential to make our roads safer, there are still a lot of bugs to work out with the technology, and questions to answer regarding its use. The only thing we can say with any certainty is that it's going to be a long time before the human element is completely taken out of the driving equation.

ABOVE LEFT: Volvo has been working on self-driving technology, using sensors that keep track of the road and surroundings

ABOVE RIGHT: Roborace allows driverless technology to be tested, without putting drivers' lives in jeopardy

Rob Banino is a freelance science and technology writer.

VOLVO, ROBORACE ILLUSTRATION: BEN THE ILLUSTRATOR

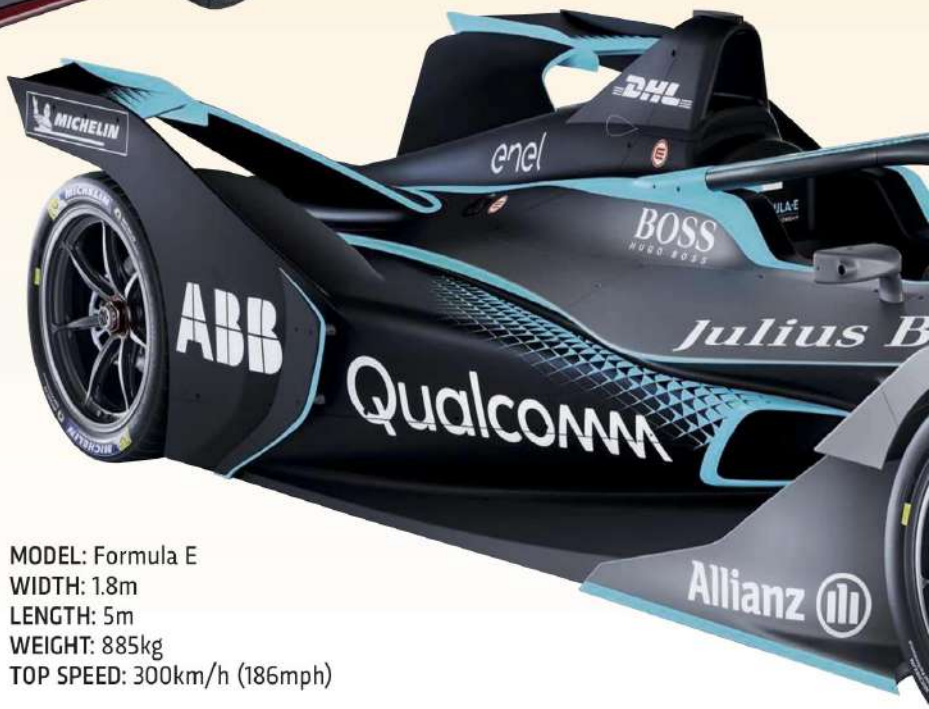
DIESEL ISN'T DEAD

With increased diesel taxes and bans being introduced to cities all over Europe, it's no surprise that some manufacturers are ending production of diesel vehicles. But Mercedes claim diesel isn't dead yet. Fans say the Mercedes C300de plug-in diesel hybrid marries the best of diesel with low urban emissions, but we'll have to wait and see whether diesel hybrids will have a place among the upcoming diesel regulations.

ROAD TO THE

ABOVE: The I-Pace is Jaguar's first fully electric car

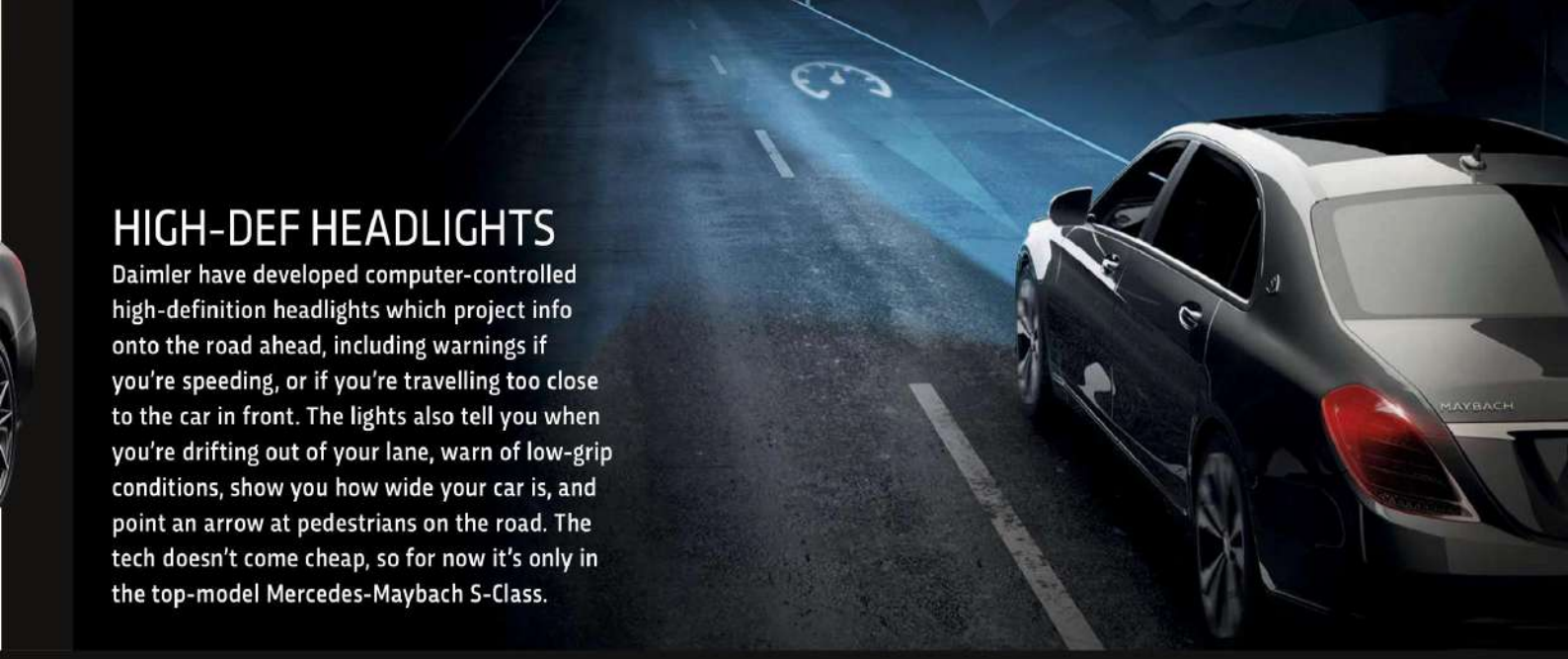
BELOW: This Formula E model was built by French company Spark Racing Technology to compete in the electric car equivalent of F1. Its battery, supplied by McLaren, has double the capacity of the previous model, which means drivers will no longer need to switch to a second vehicle halfway through each race



MODEL: Formula E
WIDTH: 1.8m
LENGTH: 5m
WEIGHT: 885kg
TOP SPEED: 300km/h (186mph)

TAKING ON TESLA

The Geneva Motor Show was full of challengers to Tesla's luxury electric vehicle dominance, but the Jaguar I-Pace outpaced the rest. It's Jaguar's first fully electric vehicle and matches up with Tesla's entry-level Model X, with similar specs at a lower price. Porsche, Audi and BMW all showed off their upcoming electric models, but Hyundai summed it up best with a giant billboard for its new Kona Electric that read: "Your turn, Elon".



HIGH-DEF HEADLIGHTS

Daimler have developed computer-controlled high-definition headlights which project info onto the road ahead, including warnings if you're speeding, or if you're travelling too close to the car in front. The lights also tell you when you're drifting out of your lane, warn of low-grip conditions, show you how wide your car is, and point an arrow at pedestrians on the road. The tech doesn't come cheap, so for now it's only in the top-model Mercedes-Maybach S-Class.

FUTURE

While driverless vehicles are still being tested, here are the latest developments for regular cars that were showcased at the Geneva International Motor Show earlier this year…

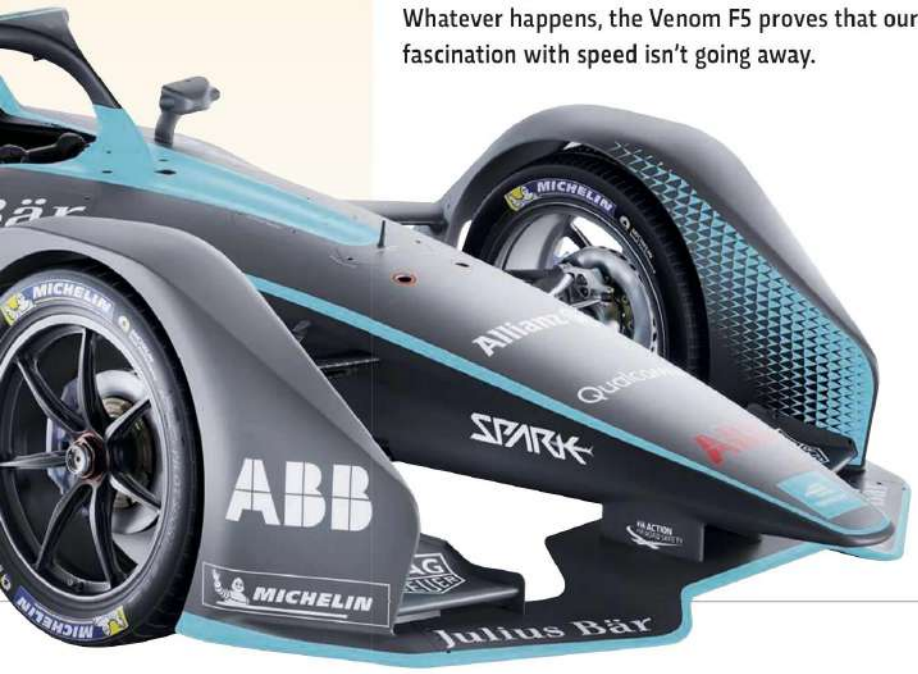
WORDS: **JASON GOODYER**

NEWSPRESS, FIA/FORMULA E

ABOVE: The Venom F5 could be capable of taking down what's regarded as one of the last achievable road records – going faster than 300mph

THE NEED FOR SPEED

The race to break the 300mph (482km/h) barrier is heating up, with Hennessey producing the latest candidate. Company founder John Hennessey claims that the Venom F5 – with its 1,600 horsepower, twin turbo V8 engine – can push all the way to 301mph. Whatever happens, the Venom F5 proves that our fascination with speed isn't going away.



SUBSCRIBE AND DRIVE

With the hybrid Polestar 1, Volvo has replaced the traditional own-your-own-car model with an all-inclusive yearly subscription that covers hassles like insurance and maintenance. It has a nifty 'phone-as-key' system that allows you to open the car using an app and authorise access to others. With simple sign-ups and the ability to avoid depreciation costs, the subscription model might be the way of the future.

SUPER **TRAIN**

Hop onboard the Hyperloop express that zips along at 760mph – as fast as a plane

The vehicle is propelled using a linear electric motor. When it moves in the tube, the pressure rises and drops, and air flow accelerates and decelerates around it. The shape of the pods ensure it is as aerodynamic as possible.

We all hate commuting by train. But imagine your carriage hurtling down a tunnel at the same speed as a commercial jet airliner. That's the dream of PayPal, Tesla and SpaceX founder Elon Musk. His Hyperloop system would see passengers travel at up to 760mph on an electric-powered 'train' made up of pods that travel through a tube which acts as a partial vacuum. Musk came up with the concept a few years ago, but as his teams were too busy to work on the idea, he opened it up to anyone who wanted to develop it. Two competing companies Hyperloop Transportation Technologies (HyperloopTT) and Virgin Hyperloop One are both developing the tech, with the hope of opening the first commercial system within the next three years.

The Hyperloop would get you from London to Edinburgh in 45 minutes, compared to 4.5 hours by train.

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THE DRONE AGE

The Taranis drone: expected to enter military service in 2030

BAE SYSTEMS

UNMANNED AERIAL VEHICLES ARE TAKING OVER THE SKIES – DELIVERING PARCELS, EXPLORING THE POLES, CHASING STORMS, HUNTING FOR ANCIENT CIVILISATIONS AND PLUNGING INTO VOLCANOES. THESE RADIO-CONTROLLED FLYING MACHINES HAVE SEVERAL PROPELLERS TO KEEP THEM AIRBORNE AND COME IN ALL SHAPES AND SIZES – THE SMALLEST VERSIONS ARE USED TO SERVE FOOD AND DRINKS, WHILE MILITARY DRONES RESEMBLE SMALL AIRCRAFT. HERE WE EXPLORE THE RANGE OF ROLES THEY'VE BEEN ENLISTED FOR...

WORDS: **LUKE EDWARDS**

THE SPY

Military drones can perform surveillance over enemy territory and deploy missiles to attack targets in dangerous places where we may not want to risk human pilots. Some can take off, fly and land by themselves. One of the most advanced today is the Taranis, a UK-built drone with a top speed of 1,127km/h (700mph) and 9m wingspan that's nearly invisible to radar.

Back in 2015, a number of high-profile scientists and entrepreneurs clubbed together to issue a warning that the continued development of military artificial intelligence meant we could soon expect the third revolution in warfare, following gunpowder and nuclear weapons. Stephen Hawking, Elon Musk and Steve Wosniak were just a few of the high-profile endorsers that have joined hundreds of robotics experts in signing an open letter warning us that weapons able to search and eliminate people based on pre-defined criteria, such as armed quadcopters, are years, not decades, away.

THE MARS EXPLORER

Despite a lack of human explorers, the surface of Mars has already been mapped so accurately. This is thanks to the data sent back by NASA's rovers. However, like all wheeled vehicles, the rovers can run into problems on the landscape, such as when they're faced with slopes angled at 30° or more. Drones don't have those problems.

NASA has already developed a drone that can cope with the Martian atmosphere as well as outer space. These 'Extreme Access Flyers' won't just snap images and video, but will also collect samples. While on the planet, the flyers will use rotors and fans to manoeuvre. But in a zero gravity situation they can turn on cold gas thrusters.

These creations could be used on Earth too, at sites with heavy toxins or high levels of radiation. In the near future, the first responders at disaster sites could well be drones.

Extreme Access Flyers will have to cope with the conditions of space

THE STORM CHASER

Until recently, scientists had to get close enough to a tornado to insert their measuring kit by hand. But not for much longer. Drones could take over. A US-based team called The Sirens Project is experimenting with fixed-wing drones as a method of probing tornadoes. This type of drone was picked because of its ability to stay in the air for long periods, remain stable in high winds and achieve the 160km/h (100mph) target speed needed to punch into a tornado.

To get the data out, a company called DroneDeploy has created a device capable of surviving inside a tornado. It provides an internet-based connection with the drone and the telemetry hardware built into its wing, but also helps the pilot locate it should the tornado get the better of the drone.

Fixed-wing drones can smash into a tornado to take measurements

SIMON JARDINE/AEROBOT.COM.AU, NASA/SWAMP WORK, JAXA/NASA, AG EAGLE UNMANNED ARIAL SYSTEMS, DR GUY WILLIAMS, DR ALEX FRASER AND MS EVA COUGNAN/COURTEST OF THE UNITED STATES ANTARCTIC PROGRAM & NATIONAL SCIENCE FOUNDATION

THE POLAR PILGRIMS

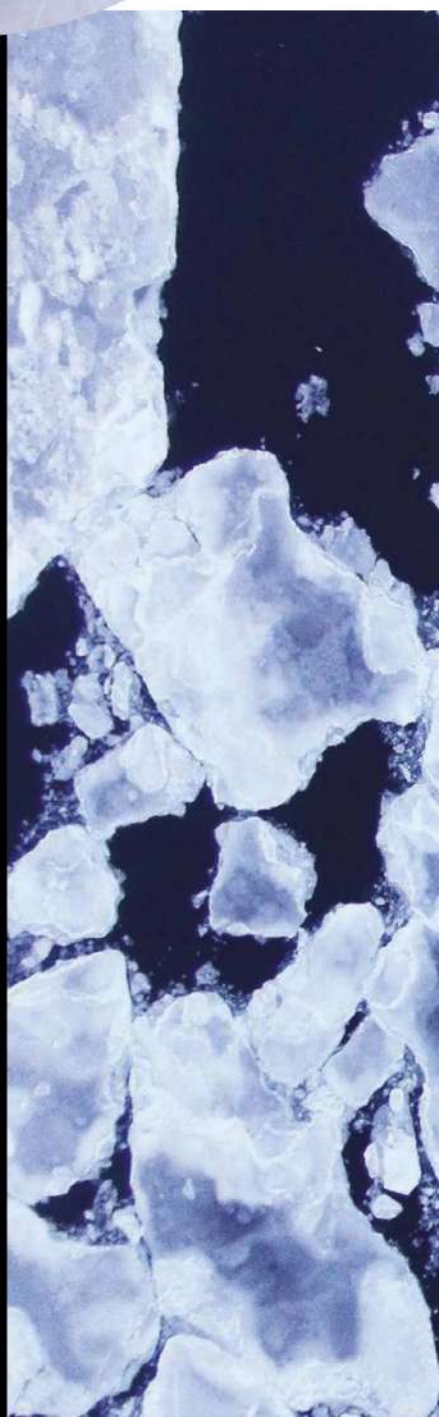
The North Pole is one of the most remote places on the planet. Despite the harsh environment, there is contention about ownership as there could be rich natural resources beneath the ice. To ensure its presence in the Arctic, the Canadian government has started working on drones capable of surviving the conditions.

Explorers have died in the sub-zero temperatures of the most northerly point on the planet, and normal drones would likely suffer a similar fate. One of the major issues to overcome, if drones are going to explore the Arctic, is direction. At the Earth's polar tip the use of GPS is difficult. For drones to successfully navigate in the region, there needs to be a 'crown' of satellites in the right positions to establish locational data.

Once navigation is solved, the drone then has to survive the cold. At temperatures of around -40°C, the reactions that batteries rely on slow to snail's pace. But it's not just chilly temperatures that stop flight – fog is a barrier too. In the Arctic, clouds and fog can undergo structural icing. This means that the water droplets crystallise on impact. Needless to say, that's a problem for a drone's spinning rotors.

Larger planes and helicopters can survive this as they're big enough to carry de-icing equipment. But this just isn't an option for the smaller drones.

The work of the Canadian government is still in its infancy but it currently looks like drones will act as assistants to manned missions. These could find the fastest way around a landmass, saving time, resources and potentially even lives.

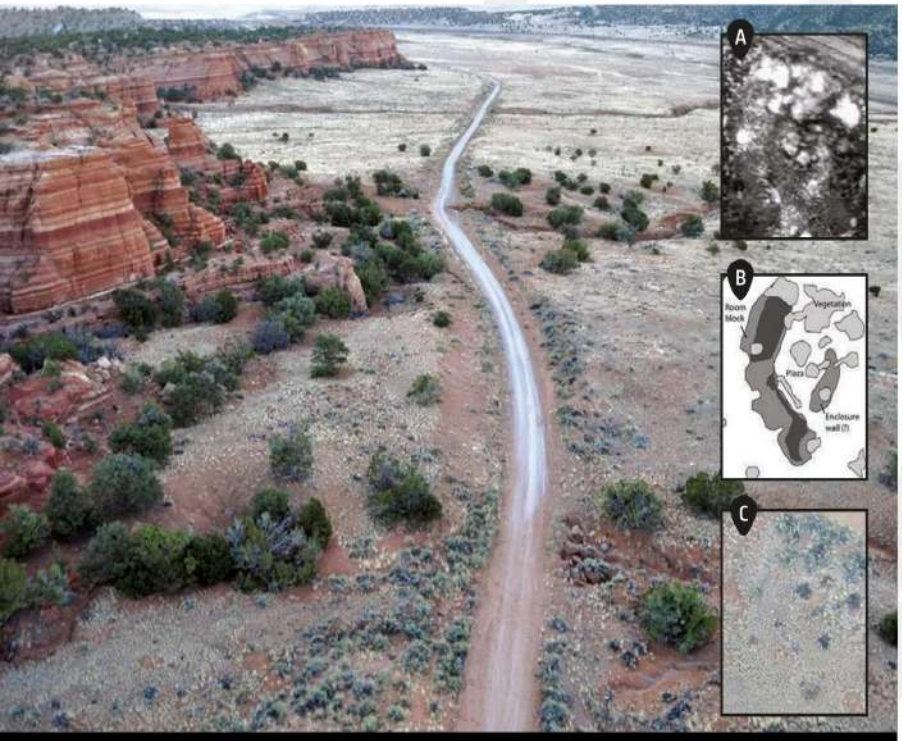


The Internal Ball camera lives in the 'Kibo' science module on the ISS

THE SPACE SHOOTER

This cute drone, which looks a bit like *Wall-E*'s Eve, lives on the International Space Station (ISS). The Internal Ball Camera takes photos and videos of the astronauts at work, relaying the shots in near real-time to scientists at the Japan Aerospace Exploration Agency (JAXA). The untethered drone floats around in the zero-gravity environment and is operated from Earth. As astronauts spend around 10 per cent of their time photographing or videoing their work, the hope is that this will free up their hands to make them more efficient.

Near the South Pole, the United States Antarctic Program has been trialling drones to map the changing sea ice. The UAV that took this picture was paired with an autonomous sub below the ice. This allowed a team to produce a photo mosaic of an ice field out of 500-1,000 images



ABOVE: Thermal images from Blue J (A) can be used to create an interpretation of the region (B) far more effectively than a standard photo (C)

THE CIVILISATION HUNTER

Ironically, the destruction of the Amazon rainforest has breathed new life into our understanding of ancient civilisations. Deforestation has revealed over 450 geoglyphs – patterns left in the ground by former civilisations. These patterns could reveal if societies prior to the 1490s were small bands of hunter-gatherers and shifting cultivators, or more complex civilisations.

To find out we need to investigate how the patterns are spread over a 5,500,000km² area of thick rainforest. Covering that on foot would take lifetimes and when you consider the potential diseases, wildlife attacks and dramatic weather you'd encounter, one life per person might not be enough. This is where drones can help.

One project, led by UK scientists, employs drones to fly over the Amazon. The drones are equipped with a LiDAR and multispectral sensors, which can see through the dense canopy of leaves and branches that forms the rainforest's ceiling. The LiDAR works by bouncing light off objects to build an image. Throw in some algorithms to factor in light reflecting off the leaves and you're left with a pretty clear image of what lies beneath, on the forest floor.

This isn't the only place where old civilisations are being revealed by drones. A 1,000-year-old Native American settlement dubbed Blue J was recently discovered in the desert of New Mexico. By flying a drone equipped with infrared cameras, archaeologists were able to see through the vegetation to paint a picture of the former civilisation underneath. By comparing drone images, archaeologists are now able to recognise various materials so they can determine where to dig more accurately than ever before.

THE VOLCANO VOYAGER

Volcanoes can spew out lava at temperatures of up to 1,200°C. This searing heat, combined with choking gases, makes them tricky to study. But now, specially equipped drones are allowing us to take a closer look inside.

We have Australian drone specialist Simon Jardine, with his company Aerobot to thank. They constructed a drone that could not only create 3D maps of volcanoes but also survive the extreme temperatures, corrosive fumes and spinning winds above them.

It was no easy feat. In order to map Vanuatu's Marum Crater, Jardine and his team lost several drones and cameras. The prolonged exposure to acidic clouds crippled electronics, while the shifting hot and cool air sent at least one drone smashing into the crater wall. Eventually, by using DJI Phantom drones and GoPro cameras, rendered via Pix4Dmapper, the team virtually recreated the crater.

More drone volcano footage has since emerged. Drone specialist and photographer Eric Cheng recently acquired some stunning 4K shots of active volcanoes in Iceland at the point of the biggest eruption in 200 years. His team flew two DJI Inspire 1 drones through buffeting thermals to capture the active volcano as never seen before. They even landed one on the lava flow.


A drone braves the searing heat of an erupting volcano to capture 4K footage

JESSE J CASANA, GETTY, ERIC CHENG/FERDINAND WOLF, RYAN DEBOODT

Drones helped to map the enormous Hang Son Doong cave in Vietnam





THE CAVE DWELLER

Vietnam's Hang Son Doong cave is enormous, and the prospect of mapping it is daunting. Its main passage is over 5km long, 150m wide and 200m high. Despite its incredible size, the cave was only discovered in 1991. The Cave of the Mountain River, as its name translates to, was stumbled upon by a local man after he heard the whistling of wind and the roar of its river. Until then, the perilously steep descent of the entrance had kept humanity at bay.

At some point the roof of the cave collapsed, leaving two large holes that let in sunlight. Trees and other vegetation have flourished in these sunny spots, making the cave look almost inviting. But climbers wanting to explore and map the cave came across some tricky obstacles. One person who entered the cave early on described climbing 6m blades of limestone to circumnavigate the 150 networks of connected caves. They were ultimately stopped by a 60m wall of muddy calcite.

Time for the drones. Beijing-based photographer Ryan Deboodt sent his DJI Phantom II drone equipped with a GoPro Hero4 into the cave's depths to get a better look. He successfully managed to snap clear views of the cavern. The ability of drones to move freely at speed highlights just how much more adept they are at exploring than humans. From August each year, heavy rains cause river levels to rise in Vietnam, making caves like these largely inaccessible for humans. But drones can explore caves all year round.

BBC RADIO 4

Listen to a clip discussing the legal restrictions for flying drones
bbc.in/2u20FnP

Luke Edwards is a technology writer.

FLY INTO THE FUTURE

CHECK OUT THE COOL WAYS YOU'LL TAKE TO THE SKIES...

HOVERBOARD

Zapata's new jet-powered hoverboard can reach heights of 3,000m, travel at 140km/h (87mph), and is reportedly being eyed-up by the US military. Zapata's Flyboard Air (pictured) can manage a brief 6- to 10-minute flight on a full tank of fuel, long enough to travel around four kilometres. Franky Zapata is the only pilot trained to demonstrate it. But the company also has the safer EZ-Fly, which you can fly. All you need is a cool £213,000.

ZAPATA

FLYING CAR

You wait 50 years for a flying car, and then three come along at once.

First up is Vahana: an Airbus project to develop battery-powered, single-seater aircraft, designed to follow predetermined routes, only deviating to avoid collisions. Swivelling rotors on the wings will let it take off and land without a runway. Last November, Airbus announced that it's ready to begin flight tests.

Second, Dubai began testing autonomous air taxis last year, as a way to beat the UAE's notorious traffic jams. The Volocopter is an electric multi-copter with 18 rotors and a fully autonomous control system. It's essentially a scaled-up drone with two seats and up to 30 minutes of flying time.

But if you want something more like the wingless flying cars of 1950s sci-fi that go direct from point to point, try Urban Aeronautics' Fancraft.

Earlier flying cars needed runways to take off and land, but that was not much better than using a separate car and aircraft. To go from point to point requires vertical take-off and landing, but for decades that could only be done by helicopters or larger aircraft. Urban Aeronautics' solution is to use light but powerful engines, lightweight composite materials, and automated flight controls. Their ducted fan design is powerful but unstable, so the Fancraft would be challenging for a human to fly unaided. Instead, computer-aided control tech takes over the tiny, split-second adjustments required to keep the car stable at speeds of 160km/h (100mph) or more.

The wingless Fancraft resembles the vision of the classic flying car

PERSONAL DRONE PLANE

The Flyer is a lightweight, single-person drone plane that you can pilot yourself after just a few hours of training. It has 10 battery-powered propellers and weighs 113kg. The pilot has two controls: a joystick for direction, and a slider for speed, with no other instruments or screens. An onboard computer takes care of the tough job: keeping the Flyer level. In the US, the Flyer falls into the Federal Aviation Authority's ultralight category, which means it can be flown without a pilot's licence, but only in uncontrolled airspaces. But, with a maximum elevation of three metres and a top speed of 32km/h (20mph), the current Flyer has limited use, especially as the battery can only power 20 minutes of flight at a time.

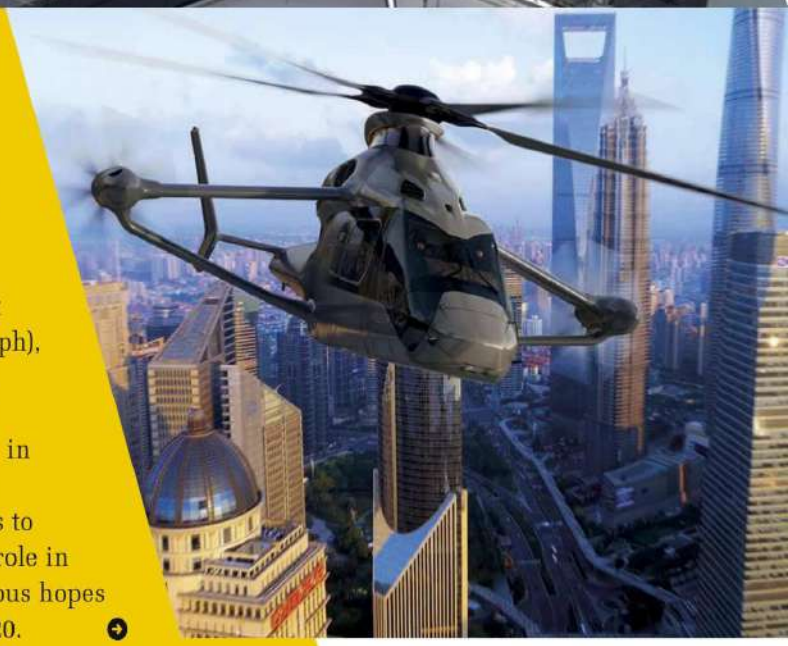
The Flyer has a top speed of 32km/h

KITTY HAWK, AIRBUS

WINGED HELICOPTER

Airbus has been developing a new Racer concept helicopter, which has both a main rotor and a pair of propeller-sporting wings. Racer (an acronym for 'Rapid and Cost-Effective Rotorcraft') would take off vertically, just like a normal helicopter, but would boast a top speed of 400km/h (250mph), which is nippier than traditional choppers.

The craft is designed for the operation of high-speed passenger services, particularly in urban areas where its vertical takeoff and landing capabilities will speed up transfers to and from airports. But it could also find a role in military search-and-rescue operations. Airbus hopes to have a commercial craft available by 2020.



AIRSHIP

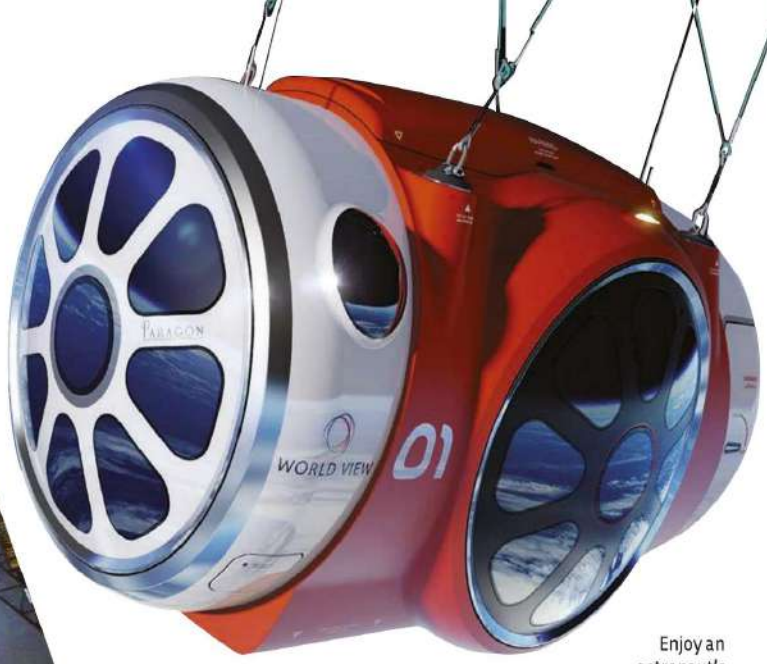
If you've heard of the Hindenburg disaster, you'll probably question the advisability of firing up massive passenger balloons filled with flammable gas. But modern airships are filled with helium rather than hydrogen, and can fly for thousands of kilometres while burning less fuel than an aeroplane. The UK-built Airlander 10 is actually a hybrid, using helium to provide 60 per cent of its lift, while the rest is provided by its wing-like hull. The first airships have been given government grants to investigate whether they could replace long-haul freight trucks and cargo ships, but the company also has more ambitious plans for tourism.

JETPACK

Ready for your own Optionally Piloted Hovering Air Vehicle? New Zealand-based Martin Aircraft Company has your back. Okay, it's the size of a small car and uses fans rather than jets, but it has a roll cage, parachute and can stay in the air for half an hour. Sadly, there's still no firm on-sale date.

GETTY, WORLD VIEW ENTERPRISES, MARTIN JETPACKS

What's bigger than a football pitch, can withstand bullets, and has been designed in the UK? The Airlander, that's what...



Enjoy an astronaut's view of Earth

SPACE BALLOON

If you want to take a trip into space, your quickest bet might be to take a balloon. The company World View Enterprises wants to send tourists into the stratosphere, 32km above Earth, on hot air balloons. Technically passengers won't reach 'space' (which is defined as 100km above sea level), but this altitude is high enough to witness the curvature of the Earth. The balloon is still in the testing stage, but tickets should be on sale soon-ish.

A long nose and small wings, as seen in this artist's impression, cut down on noise-inducing pressure waves

X-PLANE

When Chuck Yeager broke the sound barrier in the Bell X-1 in 1947, a sonic boom rang out that battered the eardrums of anyone underneath the plane's 20-second supersonic flight path. Now, NASA has just announced funding for its latest X-plane, a commercial jet capable of flying at those same supersonic speeds (faster than the speed of sound), without disturbing the peace below.

NASA has awarded Lockheed Martin a $247.5m (£183m approx) contract to build a working example of a prototype it's been working on for a few years: the Low Boom Flight Demonstrator.

Concorde was the first commercial supersonic jet, but it was soon banned from flying supersonic over land because of the defeaning noise. Lockheed Martin says the X-plane shockwaves should sound no worse than a car door closing. NASA plans to start flying the plane by 2022, with testing over highly populated areas completed by 2025.

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THE NEXT GIANT LEAP

The ultimate voyage would be to journey out of our Solar System. An Earth-like planet has been discovered orbiting our nearest star after the Sun. Current tech could take around 70,000 years to get there. So what might be an alternative means of transport?

ANTIMATTER ROCKETS

Antimatter is the staple fuel source in Star Trek. This notoriously volatile substance is the perfect fuel in one sense because it converts matter into energy with 100 per cent efficiency, so it can release vast amounts of oomph.

In 2006, NASA funded research into a possible antimatter spacecraft. The work concluded that a ship could be propelled to Mars in just 45 days, using just one-hundredth of a gram of antimatter.

In 2003, physicist Gerald Jackson and nuclear engineer Steven Howe published their own study. It showed that with 17g of antimatter, a spacecraft could cross one light-year of space in just a decade. So, the nearest star system, Alpha Centauri, could be reached in about 40 years.

But there's a catch. Antimatter is the most expensive substance on Earth. Back in 1999, NASA estimated that to create a single gram of it would cost $62.5tn. Even today, the cost is hovering around a trillion dollars. This is because tiny quantities of antimatter are created as a by-product in particle accelerators, which are super-expensive to start with. Of all the particle accelerators in the world, including the Large Hadron Collider at CERN, less than 20 nanograms of antimatter have been made.

Storage is another problem. Antimatter is the opposite of matter. The antimatter equivalent of an electron is called a positron. Although it contains the same mass, its electrical charge is opposite. When a positron and an electron meet, they annihilate each other back into energy. So trying to store antimatter in something made from matter is doomed to explosive failure. But since antimatter carries an electrical charge it can be deflected by a magnetic field. This means antimatter could be stored in something with a magnetic lining to stop it touching the sides.

2 The capsules are shot from their storage areas into the nozzle compartment many times a second

3 Inside the compartment, a capsule's magnetic field turns off and the antimatter annihilates with the lead casing

4 The lead casing produces X-rays that gradually vaporise the nozzle's lining, producing an exhaust that pushes the spacecraft forwards

5 The nozzle is kept well away from the crew compartment and instruments, because of the high-energy radiation it produces

WHERE SHOULD WE GO?

Proxima b

For our first interstellar trip, it's a no-brainer that we should go to the nearest exoplanet, Proxima b. The Earth-like planet was discovered orbiting the red dwarf star Proxima Centauri, which lies around 4.2 light-years away. Proxima b is a rocky planet, and is close enough to its host star to allow liquid water to exist.

Kepler 452

If we had a warp drive, this star would be worth a visit. At 1,400 light-years away it is a fair distance but, in 2015, NASA announced that this star possesses a planet similar to Earth. The star itself is almost identical to the Sun, and the planet is as far from it as Earth is from the Sun. At present, it's the most Earth-like planet known.

Wolf 1061

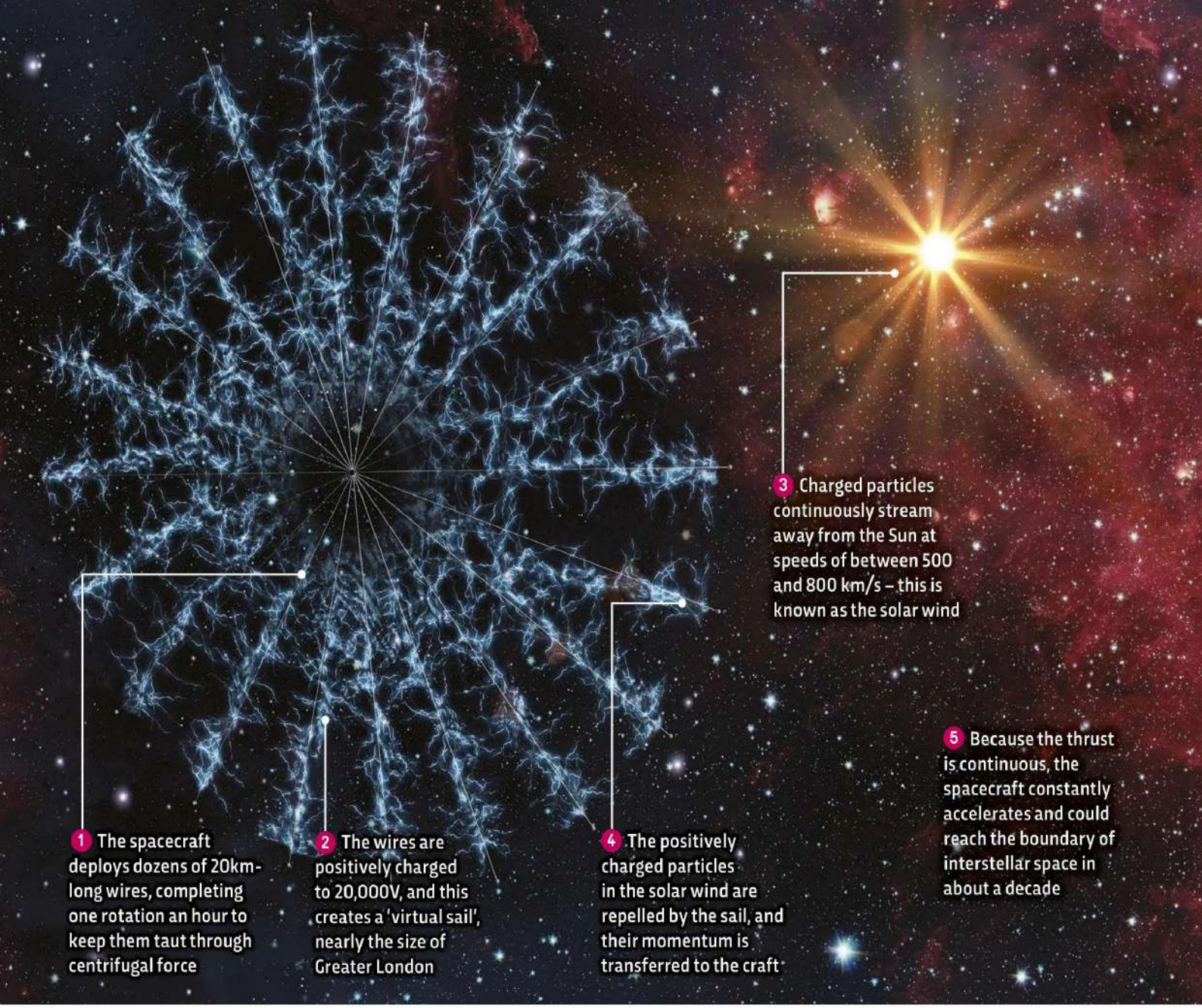
Just 13.8 light-years from Earth, this red dwarf star plays host to a potentially habitable planet. It was discovered by astronomers from the University of New South Wales in 2015 and has a radius 1.5 times larger than Earth. As its host star is smaller and much dimmer than the Sun, the planet has a far shorter orbit than Earth.

Orion Nebula

Astronomers have used telescopes to observe this faint smudge in the constellation of Orion, where thousands of stars are being formed. The Orion Nebula lies 1,344 light-years away, and whole solar systems of planets are being glimpsed, while others are being destroyed by radiation from surrounding stars.

The centre of the Milky Way

With a warp drive we could travel to the centre of the Galaxy, some 30,000 light-years away, and observe the vast black hole thought to reside there. It sits inside Sagittarius A* – astronomers would salivate at the possibility of watching as a star or a gas cloud fell into the black hole.



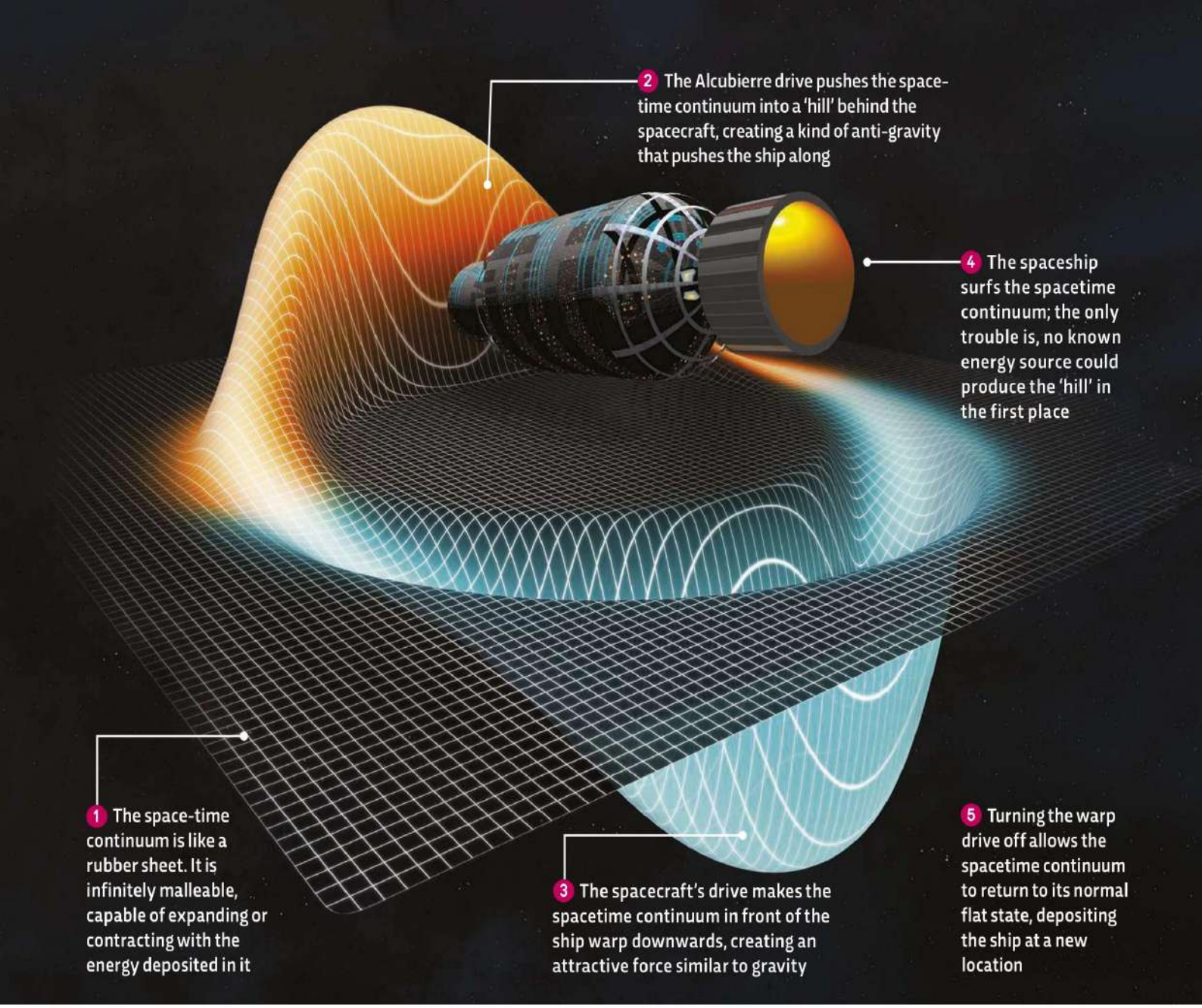
THE E-SAIL

In 1980, Carl Sagan's TV series *Cosmos* introduced audiences to his 'spaceship of the imagination' that resembled a dandelion seed floating on the 'winds' of the Universe. The concept of the electric sail is a bit similar. The e-sail is the brainchild of Dr Pekka Janhunen, at the Finnish Meteorological Institute. He conceived the idea while studying the Northern and Southern Lights, which are produced when electrically charged particles from the Sun interact with molecules in our atmosphere.

Janhunen calculated how to build a virtual sail that could harness the electrical charge from this continuous solar wind and transform it into momentum to propel a spacecraft. He imagined a central craft deploying between 50 and 100 wires, each some 20km in length. These wires would be electrified to around 20,000 volts with positive electrical charge, and so would repel the positively charged protons from the solar wind like light bouncing off a mirror. This would transfer momentum from the particles to the spacecraft.

According to the maths, a one-tonne spacecraft would be accelerated by 1mm every second. That may not sound much, but this constant acceleration would quickly add up. After a year, the terminal speed would be 30km/s. NASA's half-tonne New Horizons craft took nine years to reach Pluto; an e-sail could transport twice the mass in half the time.

The e-sail is currently being tested by NASA with plans to go further than Pluto. While it would take just 10 years to reach the very edge of the Solar System, it would still take thousands of years to reach the nearest stars.



ILLUSTRATIONS: MAGIC TORCH

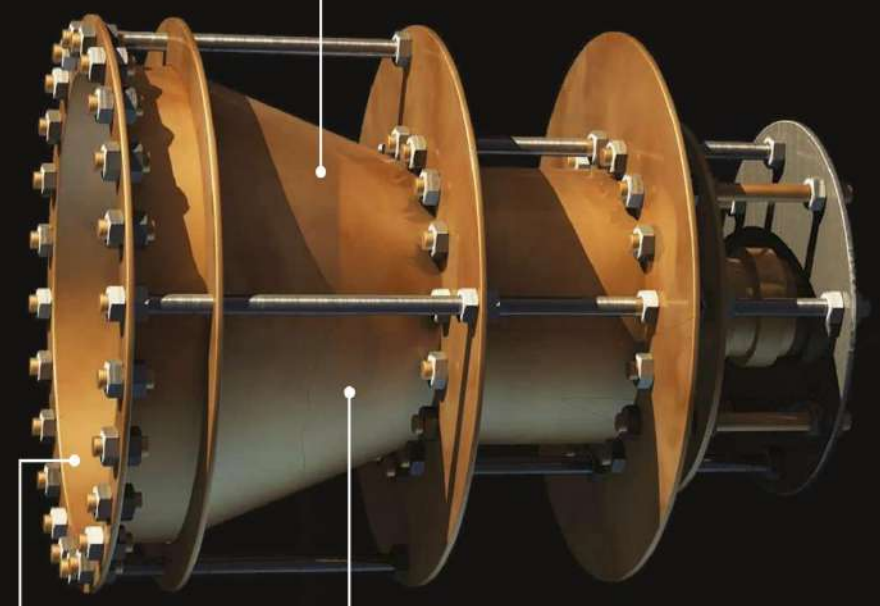
ALCUBIERRE DRIVE

This hypothetical device, again a staple of Star Trek, gets around a problem with physics, namely that nothing can travel faster than the speed of light.

Einstein's Special Theory of Relativity showed that the speed of light was a cosmic speed limit. Even though light speed is roughly 300,000km/s, that's still slow compared to interstellar distances. The nearest star to Earth other than the Sun, Alpha Centauri, is 4.3 light-years away, so light takes 4.3 years to cover that distance. Unless we can break the light barrier, it will always take longer than this to get there. This is where the warp drive comes in. It has its basis in Einstein's next theory, the General Theory of Relativity, which expanded the earlier version to include a description of gravity. Einstein found that the most natural way to explain the action of gravity was to imagine space as being like a rubber sheet. He called this the spacetime continuum. When heavy objects, such as stars or planets, were placed in the spacetime continuum, they warped it and created gravity.

In 1994, physicist Miguel Alcubierre Moya suggested there was a way to warp the space-time continuum so that it would be capable of propelling a starship faster than the speed of light. The trouble is that to make the 'warp bubble', as Alcubierre called it, the spacetime continuum would have to be warped in a way that no known natural object or energy can do.

In 1996, NASA launched the Breakthrough Propulsion Physics Program to investigate whether it would be possible to break the light barrier. But after six years and a total investment of $1.2m, the programme was disbanded.



THE PEOPLE PROBLEM

The biggest problem with spaceflight is always mass. Robotic space probes can be fairly compact and lightweight, but when you add humans, things get more complex. People need space to live and work, as well as complicated life support systems, water and food stores. Put this all together and the mass of a spacecraft skyrockets.

But what if you could send humans as cargo and revive them when the craft reaches its destination? NASA has been investigating a 'torpor-inducing transfer habitat' in conjunction with an American company called SpaceWorks Enterprises. The inspiration comes from the care of heart attack victims. For years, doctors have been inducing a sleep-state, or torpor, in such patients by lowering their body temperature. This slows the metabolism and gives a chance for their body to recover.

Now NASA is investigating whether astronauts could be kept in a torpor state for months. Their body temperature would be lowered by a few degrees by inhaling a coolant through a fluid line fed through the nose. Nutrients would be administered intravenously, and their vital signs would be monitored remotely.

NASA is already looking seriously at using this to send people to Mars, but a journey to an exoplanet would be a far more difficult proposition. Unless we make some kind of breakthrough, voyages could take decades or centuries – that's a long time to be asleep.

ELECTROMAGNETIC DRIVE

How about a thruster that uses no fuel at all? Most physicists say the electromagnetic (EM) drive is a fantasy – but it could be a game-changer.

When we launch a craft, most of its mass is the fuel. The Space Shuttle was 16 times heavier with its fuel than without. Most physicists say there is no way to get around this, because as the rocket fuel is burnt and expelled at high speed in one direction, it propels the rocket in the opposite direction. This is encapsulated in Newton's Third Law, which states that all forces have an equal and opposite reaction.

Without requiring fuel, the EM drive violates a basic law of physics and therefore cannot work. The trouble is, when people test it in the lab, it seems to work. Despite profound theoretical objections, a number of independent groups have built their own versions and tested them. These include a team from Northwestern Polytechnical University in Xi'an, China, and one from Dresden University of Technology. None have been able to rule out that the engine was producing thrust and, in 2015, NASA's Eagleworks research group reported seemingly positive results from prototypes it's built.

Critics are unconvinced. They say it is as impossible as lifting yourself off the ground by tugging at your shoelaces, and attribute the results to experimental error. It has been suggested that the EM drive works through interaction with the vacuum of space, which some physicists believe will turn out to be a seething mass of quantum particles rather than the nothing of traditional physics. But one thing is certain, it is odd that such a simple experimental setup can cause results that are so hard to explain. If the EM drive holds up to scrutiny, then it could change space propulsion forever.

Dr Stuart Clark is an astronomy writer with a PhD in astrophysics. His latest book is *The Unknown Universe*.

ILLUSTRATION: MAGIC TORCH

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